



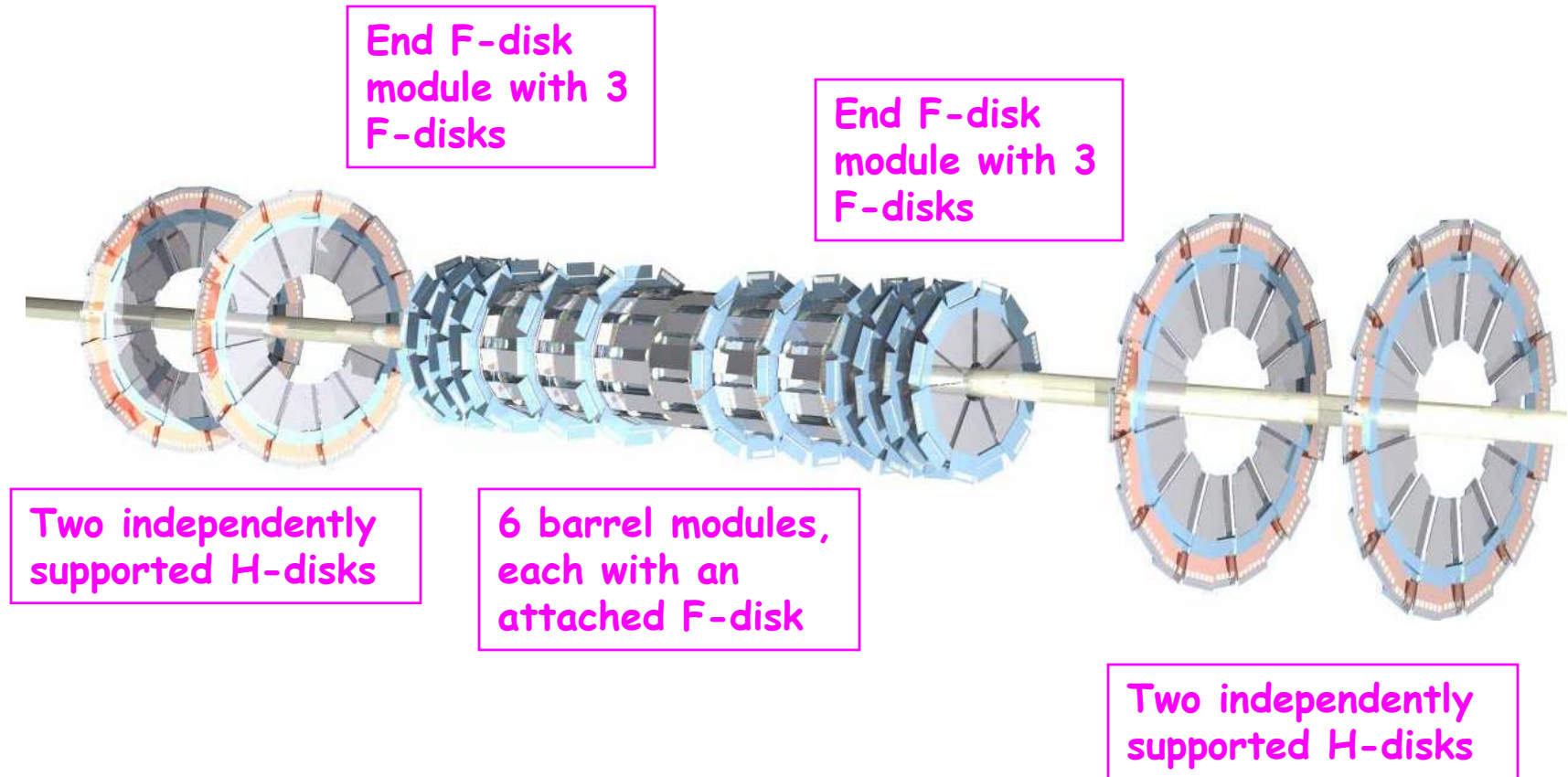
# D0 Silicon Disks

W. E. Cooper

Fermilab

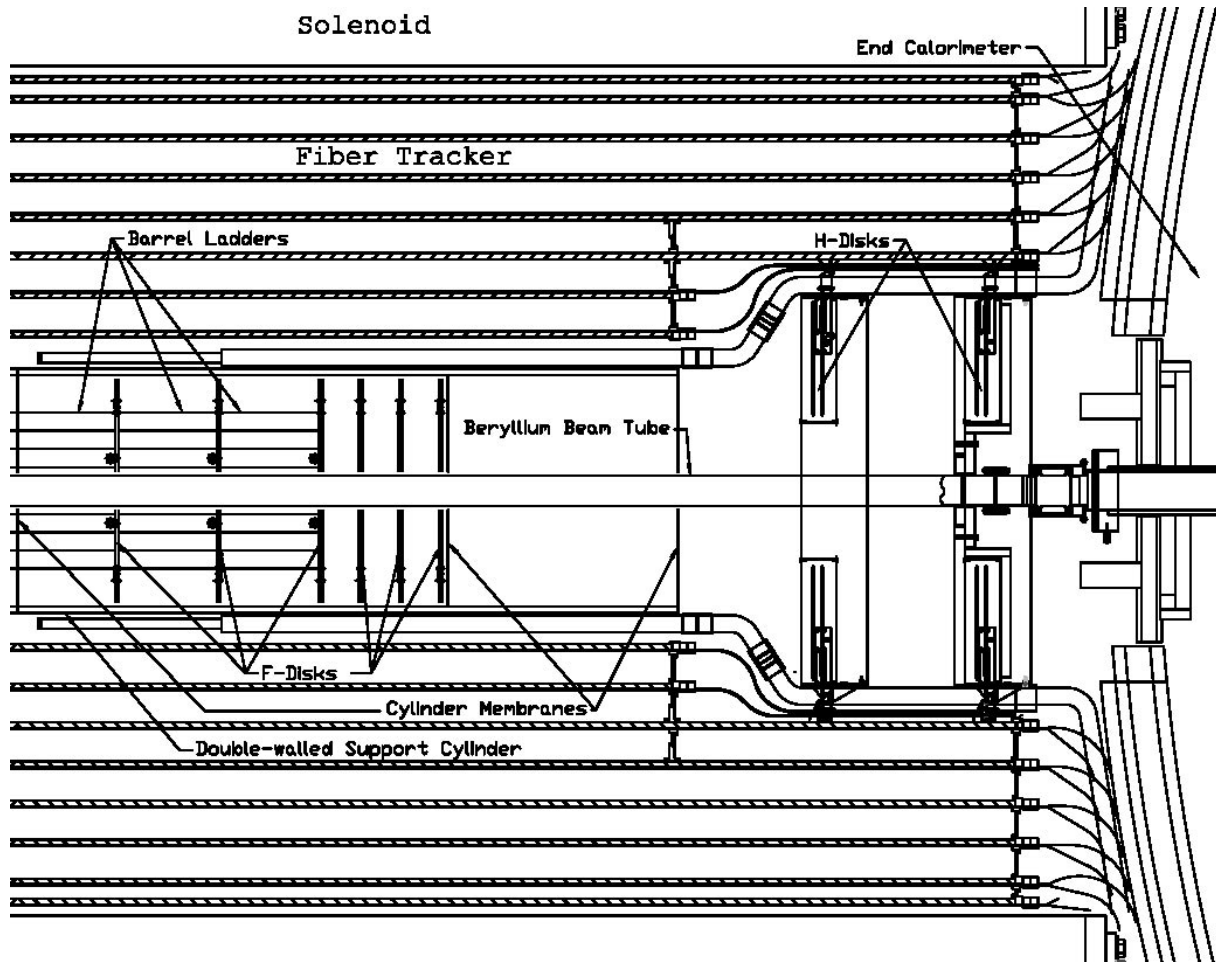


# Overall Silicon Geometry





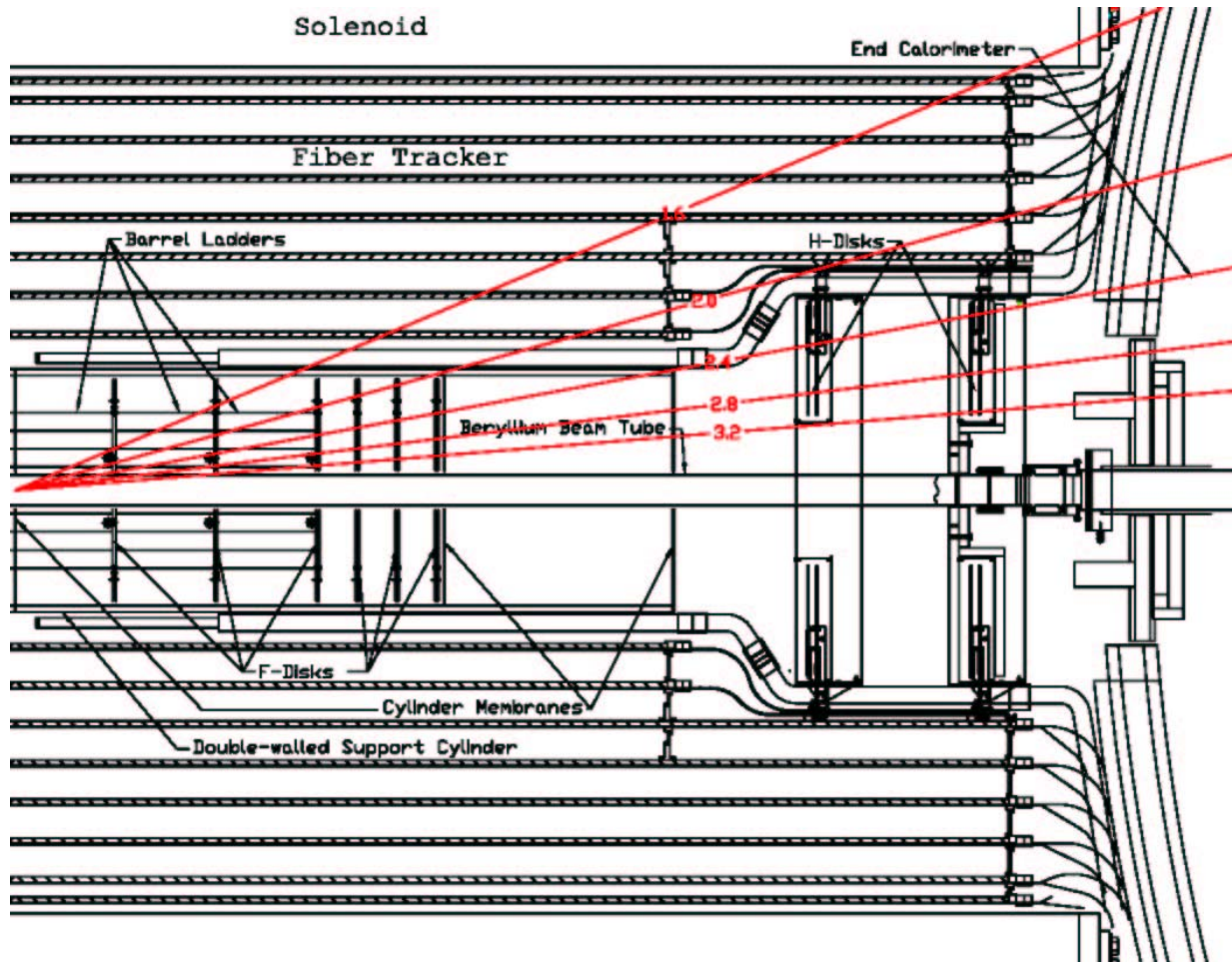
# Plan View



- Run IIa:
- Six barrels, twelve F-disks, four H-disks
- 1070 mm long barrel plus F-disk region
- 4.8 m<sup>2</sup> silicon (4.3 m<sup>2</sup> active)



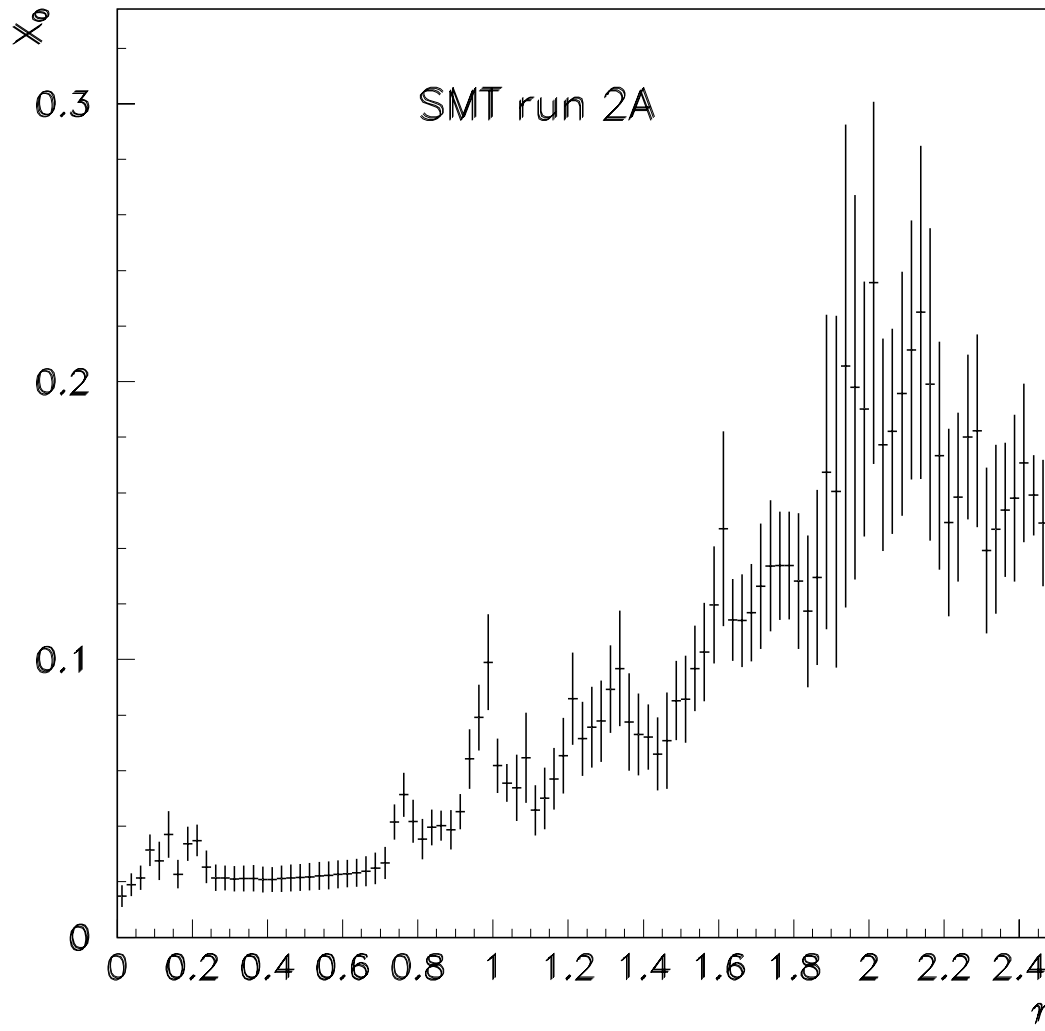
# Eta Coverage



- Interaction diamond is extended with  $\sigma \sim 30$  cm.
- For tracks originating at  $x=y=z=0$ :
- Coverage with all fiber tracker layers to  $\eta = \pm 1.6$
- Coverage with all silicon barrel layers to  $\eta = \pm 2.0$ , where end F-disks begin to supplement coverage
- H-disks supplement coverage from  $\eta = \pm 2.15$  to  $\eta = \pm 3.2$



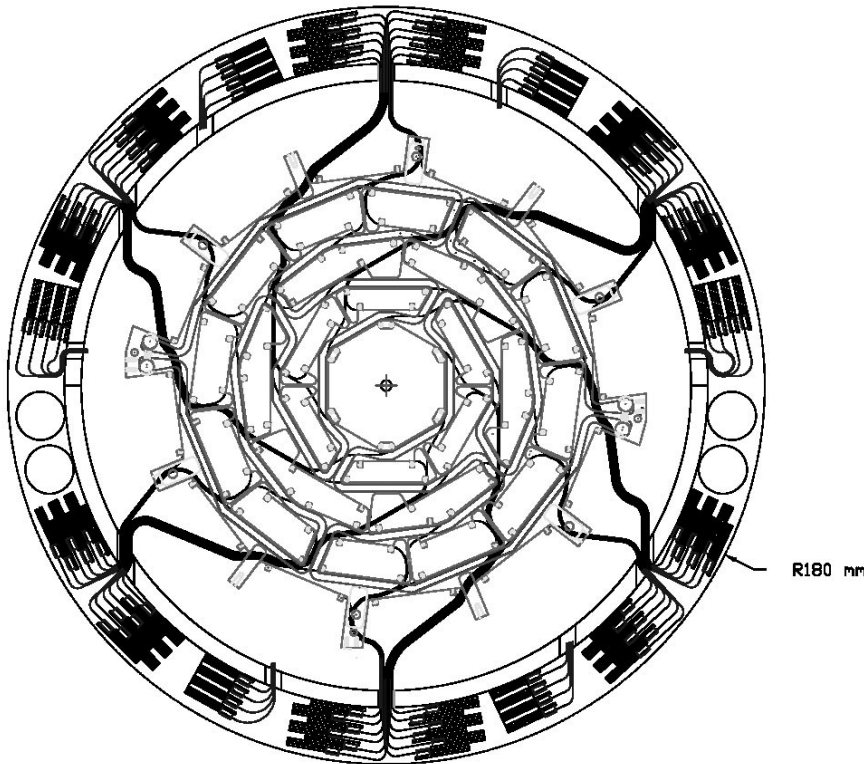
# Number of Radiation Lengths versus Eta



Flera Rizatdinova and  
Lisa Chabalina



## Silicon End View (Barrels)



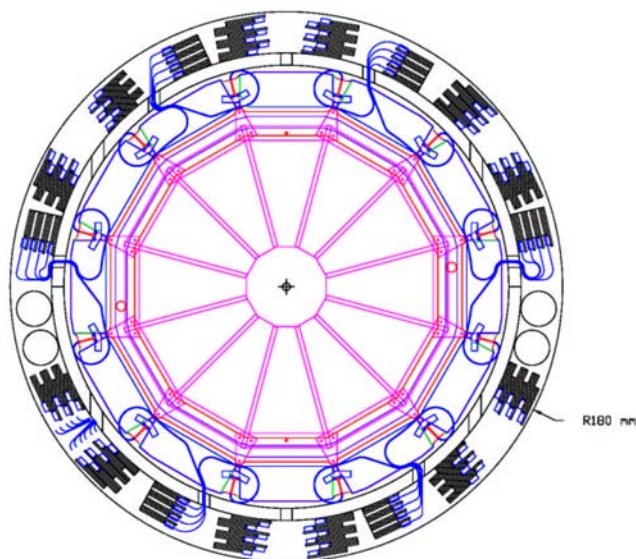
- Run IIa barrels:
- 2.6 m<sup>2</sup> silicon (2.4 m<sup>2</sup> active)
- 4 layers
- Silicon at R = 27.0 mm to 100.7 mm
- 864 sensors
- Double-sided except for layers 1 and 3 of the outermost barrels





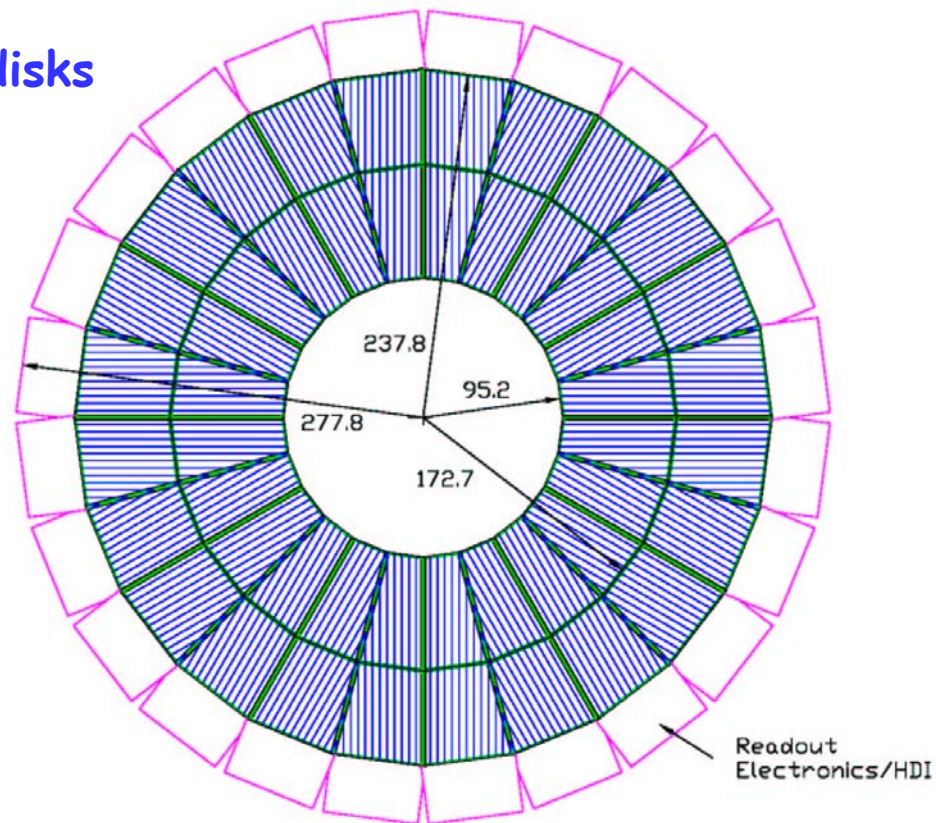
# Run IIa Disks

## F-disks



- Silicon at  $R = 27.0$  mm to  $106.3$  mm
- $0.9 \text{ m}^2$  silicon ( $0.7 \text{ m}^2$  active)
- 12 disks
- 144 sensors
- Double-sided

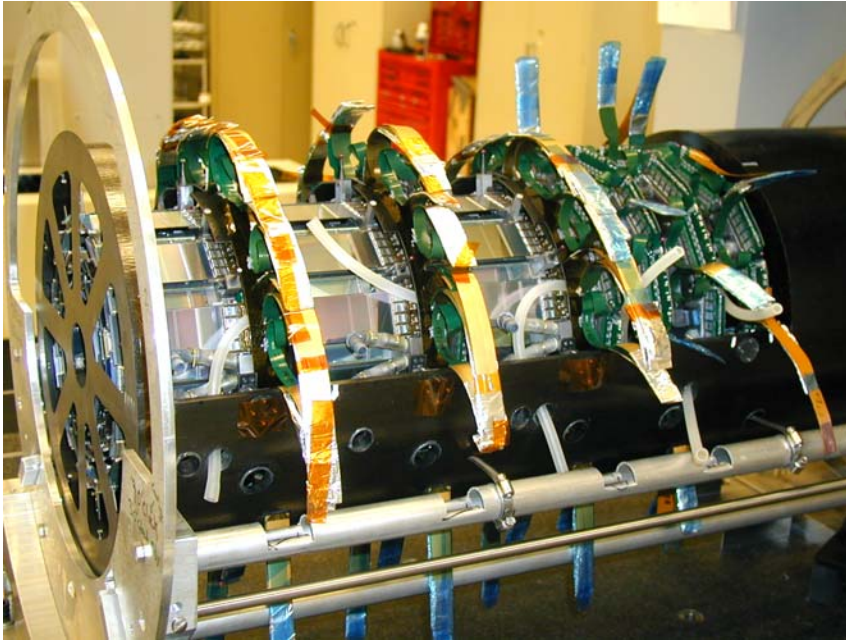
## H-disks



- $1.3 \text{ m}^2$  silicon ( $1.2 \text{ m}^2$  active)
- 4 disks
- 384 sensors
- Single-sided, mated back-to-back to form double-sided

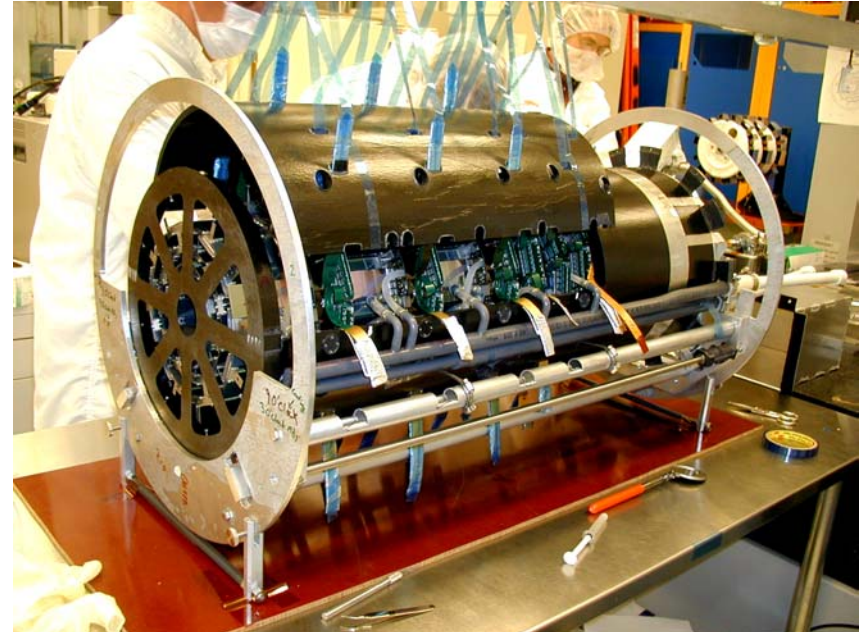


## Run IIa Silicon



Silicon modules installed in the first of two support cylinders

Nominally identical north and south silicon



Installation of the support cylinder cover

Many more fabrication and assembly photos and details were shown in Eric Kajfasz's presentation at Vertex 2002.

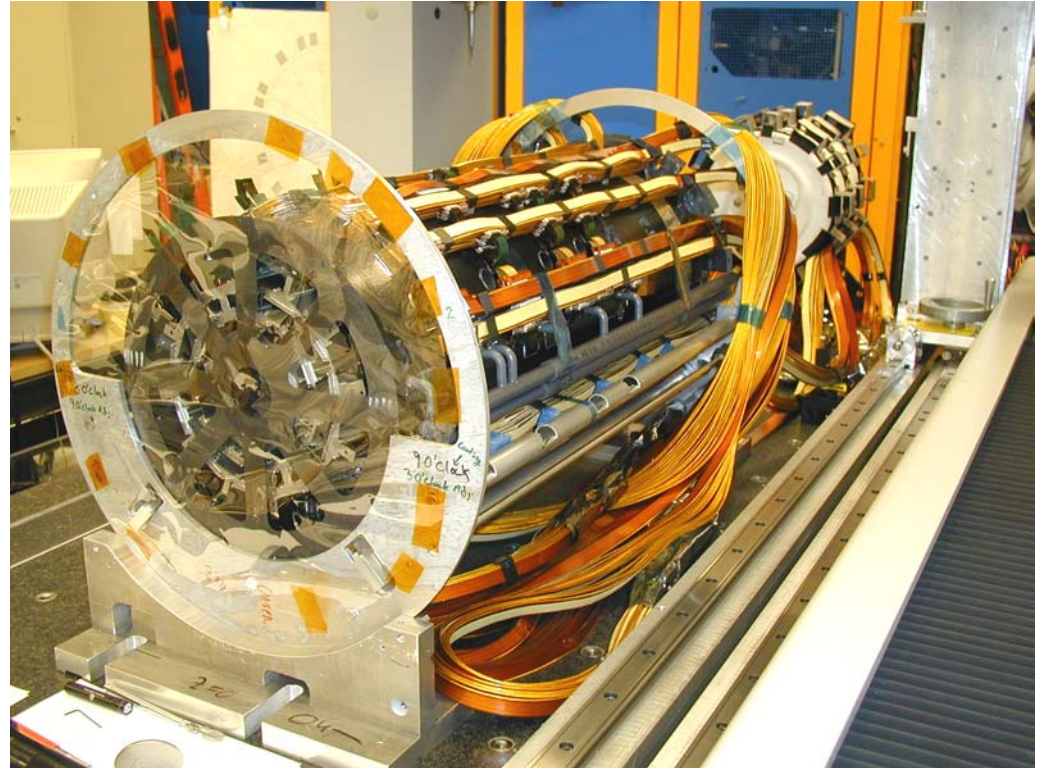




## Run IIa Silicon



After adding the initial  
few low-mass cables



Silicon cabled and ready for  
shipment



# Run IIa Sensors

- Barrel sensors were provided by Micron and CSEM
  - ♦ 144 9-chip, double-sided, 2 degree stereo sensors per barrel, 50  $\mu\text{m}$  pitch on axial surface, 62.5  $\mu\text{m}$  pitch on stereo surface
  - ♦ 144 6-chip, double-sided, 90 degree stereo sensors in the central four barrels, 50  $\mu\text{m}$  pitch on axial surface, 153.5  $\mu\text{m}$  pitch on stereo surface
  - ♦ 144 3-chip, single-sided sensors in outermost barrels, 50  $\mu\text{m}$  pitch
  - ♦ Two 60 mm long sensors, end-to-end, per ladder
- F-disk sensors were provided by Micron and Eurisys.
  - ♦ Twelve sensors per F-disk
  - ♦ Double-sided, 30 degree stereo, 50  $\mu\text{m}$  pitch on p-side, 62.5  $\mu\text{m}$  pitch on n-side
- H-disk sensors were provided by ELMA.
  - ♦ Single-sided, mated back to back to provide 15 degree stereo
  - ♦ Two back to back sensor pairs per wedge, one pair at smaller radius and the second at larger radius
  - ♦ The two sensors of a given wedge surface are wire bonded and share a common readout
  - ♦ 24 wedges per H-disk
  - ♦ 4 sensors per wedge, 80  $\mu\text{m}$  pitch with intermediate strips



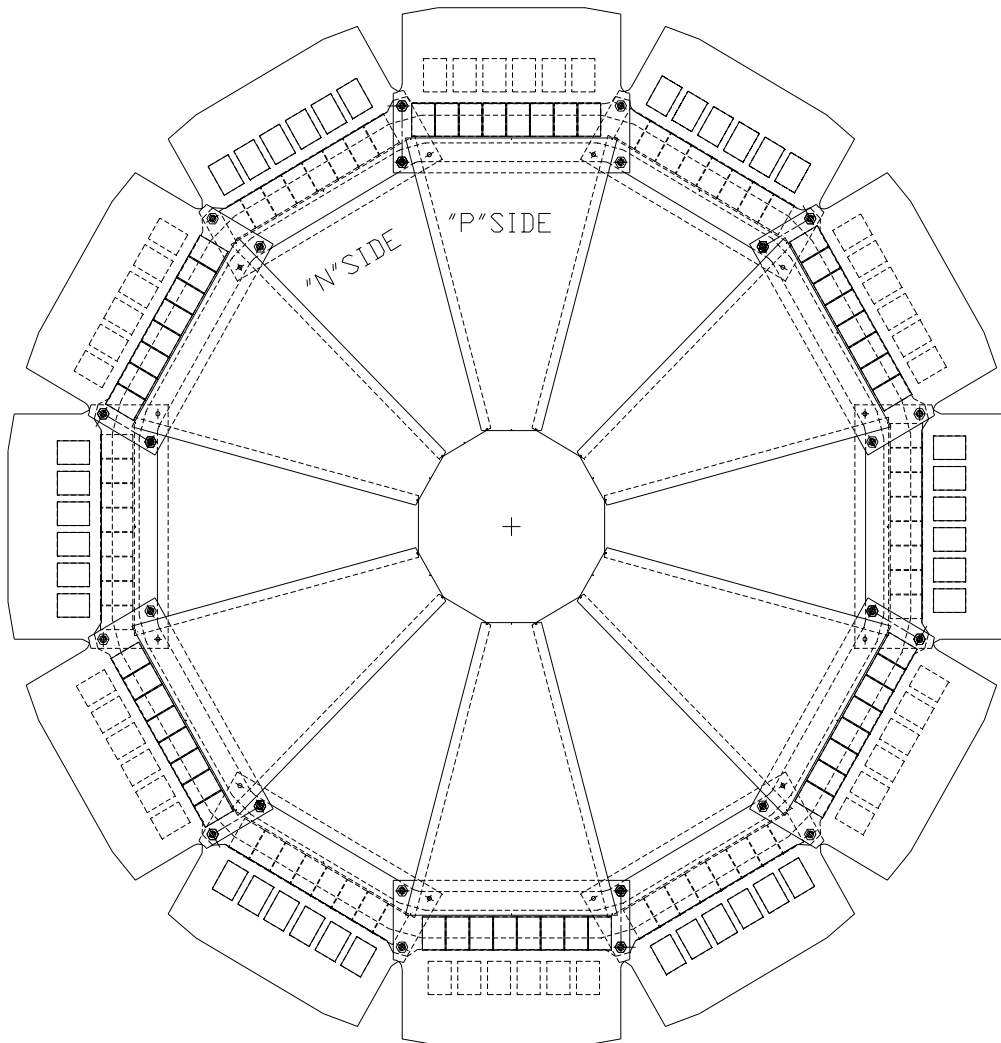
# Run IIa Sensors

D0 Silicon Tracker Parameter Table

	#	H	L1-SS	L1-DS	L2	L3-SS	L3-DS	L4	TOTAL
# detector sides	2	1	1	2	2	1	2	2	
# assys	12	8	2	4	6	2	4	6	44
R min	2.57	2.5	2.7	2.7	1.49	6.6	6.6	2.43	
R max	10.49	26	3.65	3.65	5.51	7.53	7.53	2.43	
z (minimum)	6.4	110	-12.8	-25.6	-38.4	-12.8	-25.6	-38.4	
z (intermediate) (or dz)			12.8	12.8	12.8	12.8	12.8	12.8	
z (maximum)	54.8	120	12.8	25.6	38.4	12.8	25.6	38.4	
# ladders(wedges) / assembly	12	24	12	12	12	24	24	24	
physical length/detector	7.5	14.262	6	6	6	6	6	6	
physical width (min)	1.67	2.761	2.115	2.115	3.395	2.115	2.115	3.395	
physical width (max)	5.692	6.478	2.12	2.12	3.4	2.12	2.12	3.4	
physical area (cm <sup>2</sup> )	27.6	65.88	12.72	12.72	20.4	12.72	12.72	20.4	
p side strip pitch at 1C (μ)	51.76	80.69	50	50	50	50	50	50	
n side strip pitch at 1C (μ)	64.7			156	62.5		156	62	
# IC's / p side	8	6	3	3	6	3	3	5	
# IC's / n side	6		3	4		3	4		
# detectors / readout unit	1	2	2	2	2	2	2	2	
# detectors/assy	12	48	24	24	24	48	48	48	
# detectors (total)	144	384	48	96	144	96	192	288	1392
Sides * area / assy	662.8	1581	305	610.56	979.2	610.56	1221	1958	
area / assy	331.43	1581	305	305.28	489.6	610.56	610	979	
Silicon mass (g)	278.00	884	12.6	85	205.3	85.3	170.7	410	2162
Sides * area (cm <sup>2</sup> )	7954	12649	610	2442	5875	1221	4884	11750	47387
# sets IC's/assy	24	24	12	12	12	24	24	24	
# sets IC's	288	192	24	48	72	48	96	144	
# IC's / assembly	168	144	36	72	108	72	144	216	
# IC's	2016	1152	72	288	648	144	576	1296	6192
# K channels	258	147.456	9.2	36.864	82.944	18.432	73.728	165	792.576



# F-disk Design



- Silicon IR = 26 mm, OR = 105.27 mm at wedge centerline
- Readout mounts outboard of silicon, which minimizes material encountered by tracks and allows disk to fit within a gap of 8 mm
- Wedges alternate between two surfaces of a 2.5 mm thick central cooling/support channel (beryllium)
- Effective stereo angle = 30 degrees
- p-side  
Trace angle =  $-15^\circ$  with respect to wedge centerline  
Pitch = 50  $\mu\text{m}$
- n-side  
Trace angle =  $+15^\circ$  with respect to wedge centerline  
Pitch = 62.5  $\mu\text{m}$

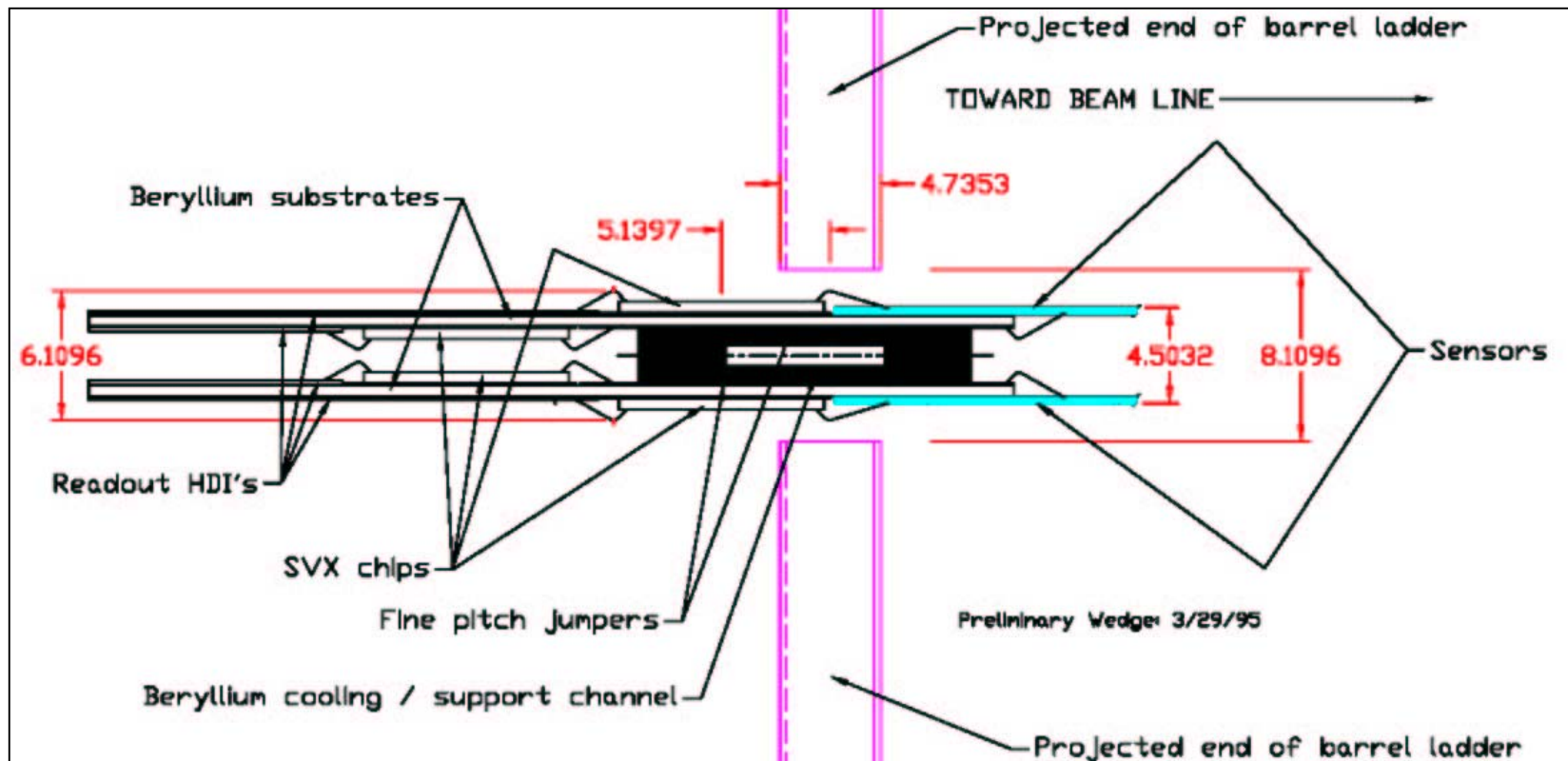




# F-disk Design

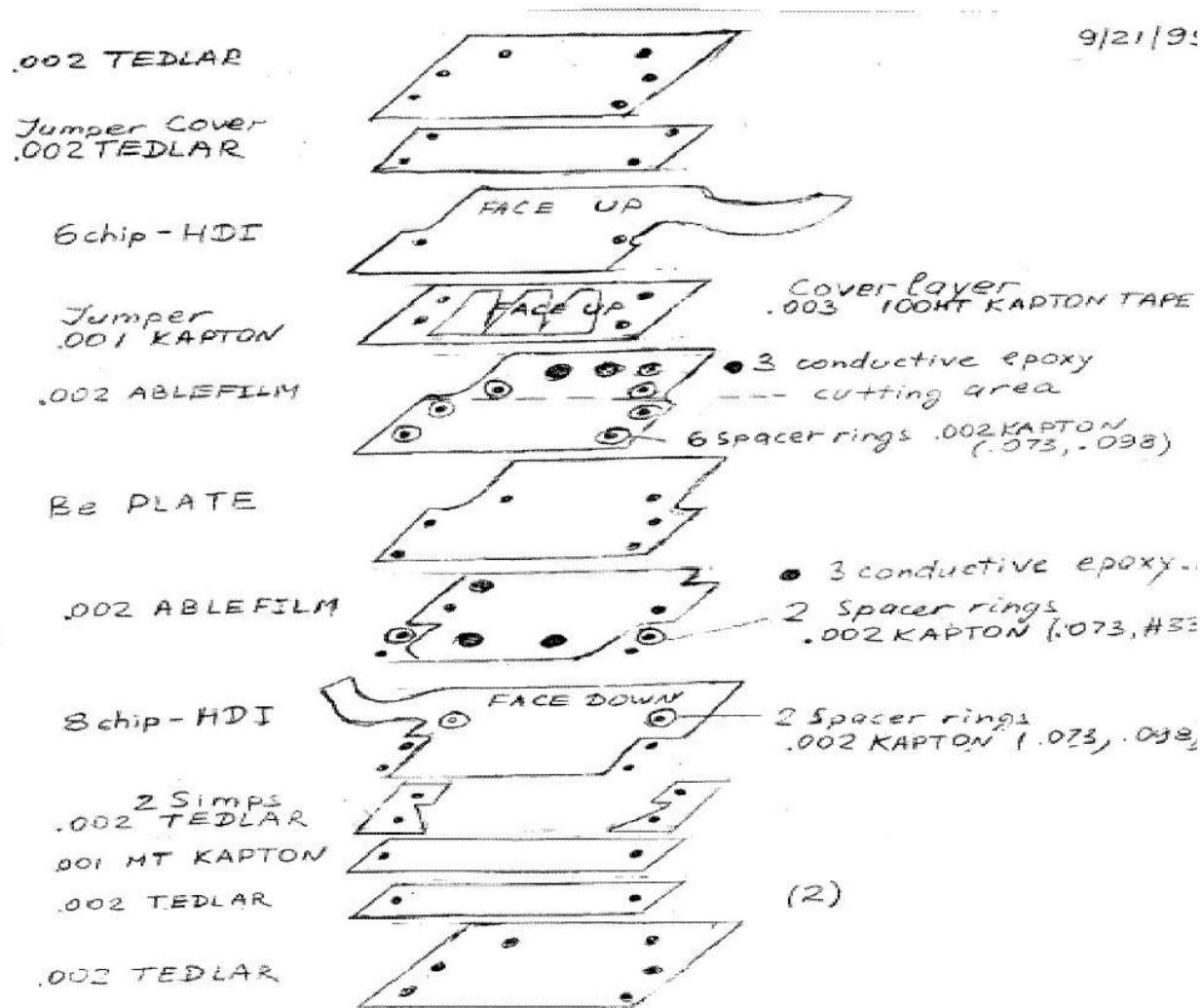
- Preliminary design drawing

- ♦ OR of sensors was increased later to allow wedge to fit closer to ladder.
- ♦ For design purposes, F-wedges on two cooling channel surfaces are drawn at a common azimuth; actual wedges are separated 60° in azimuth.





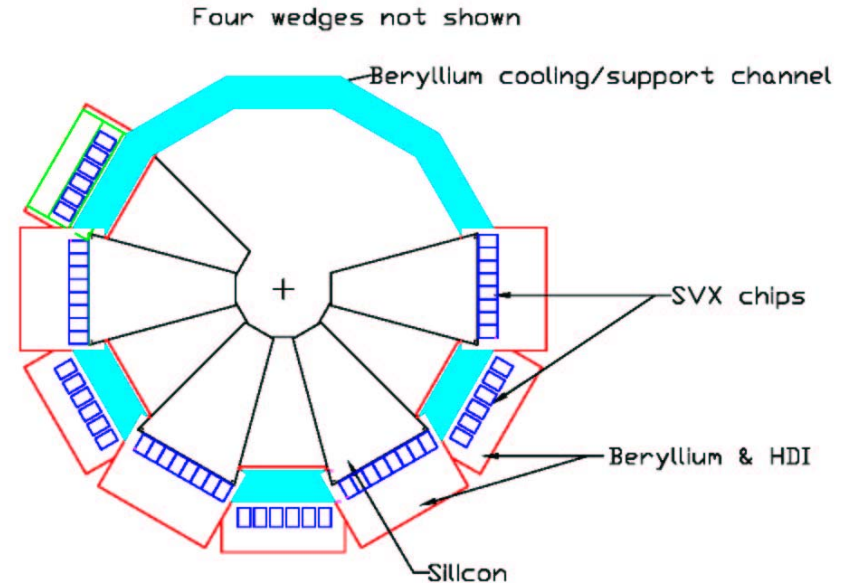
# F-wedge Lamination





# F-disk Material

Material	Silicon equivalent grams
Silicon sensor	1.926
HDI's	4.777
SVX chips	1.156
Beryllium substrates	0.754
Kapton	0.009
Epoxy	0.637
Beryllium cooling channel	1.102
Coolant	0.267
Total	10.628
Total / Silicon sensor	5.517

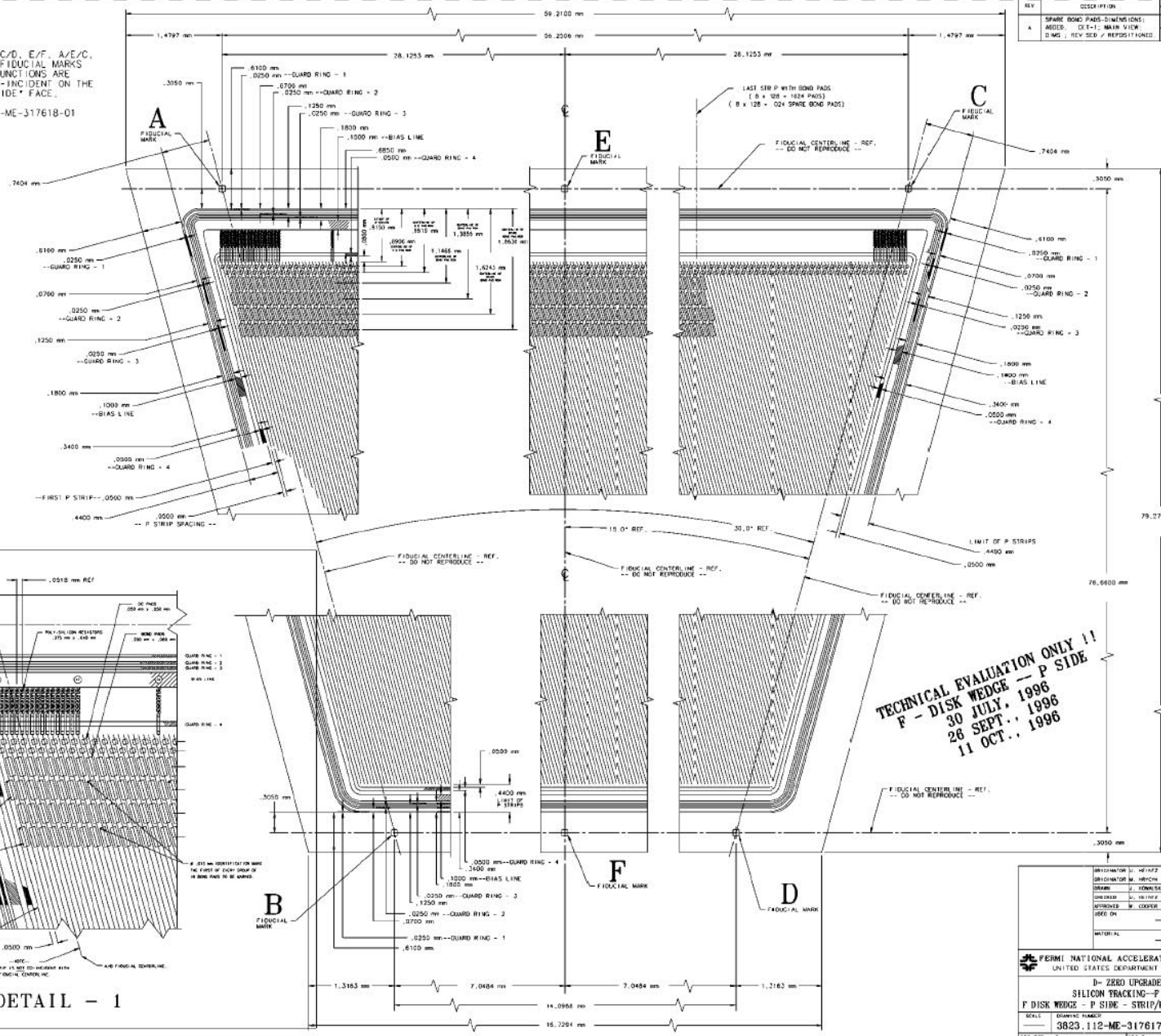


- Fraction of a radiation length = (Silicon equivalent mass) / 21.82 g/cm<sup>2</sup> / (Area of object)
- Averaged over its full extent, an F-wedge, including readout, cooling, and silicon regions, represents just under 1% of a radiation length.
- An 0.300 mm thick wedge sensor represents 0.32% of a radiation length.

NOTE:

FIDUCIAL LINES A/B, C/D, E/F, A/E/C,  
B/F/D; AND RESPECTIVE FIDUCIAL MARKS  
WHICH OCCUR AT THEIR JUNCTIONS ARE  
EQUAL AS NAMED, AND CO-INCIDENT ON THE  
-- F-DISK WEDGE -- "N-SIDE" FACE.

SEE DRAWING 3823.112-ME-317618-01



TECHNICAL EVALUATION ONLY !!  
F - DISK WEDGE - P SIDE  
30 JULY, 1996  
26 SEPT., 1996  
11 OCT., 1996

DETAIL - 1

REV	DESCRIPTION	DATE
A	SPARE BOND PADS - DIMENSIONS: METER: 0.1 x 1.0, 0.1 x 0.1 DIM: 1.0 x 1.0, 0.1 x 0.1	24 SEP 88

DESIGNER: J. H. LEE	DATE: 24 JUL 88
CHECKED: J. H. LEE	DATE: 24 JUL 88
APPROVED: W. COOPER	DATE: 24 JUL 88
DATE: 24 JUL 88	

FERMILAB NATIONAL ACCELERATOR LABORATORY UNITED STATES DEPARTMENT OF ENERGY	
D- ZERO UPGRADE F-DISK WEDGE - P SIDE - STRIP/FIDUCIAL DETAILS	
SCALE: DRAWING NUMBER: 3823.112-ME-317617-01	SHEET: REV: A
DATE: 24 JUL 88	DATE: 24 JUL 88

Revised by cooper on 09-Sep-88

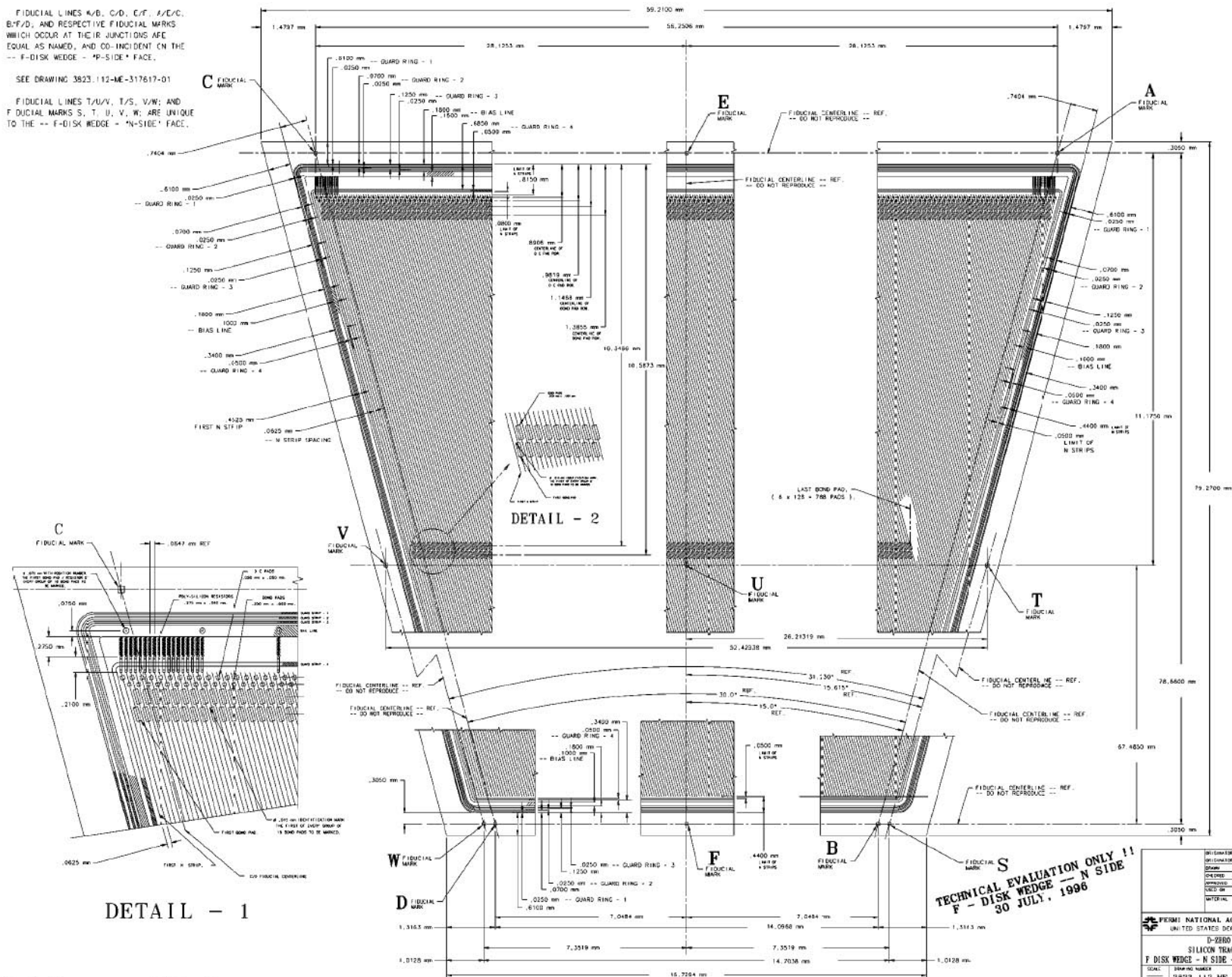


NOTE :

FIDUCIAL LINES A/B, C/D, E/F, F/G/H, B/E/D, AND RESPECTIVE FIDUCIAL MARKS WHICH OCCUR AT THEIR JUNCTIONS ARE EQUAL AS NAMED, AND CO-INCIDENT ON THE -- F-DISK WEDGE -- "P-SIDE" FACE.

SEE DRAWING 3823.112-ME-317617-01

FIDUCIAL LINES T/U/V, T/S, V/W: AND FIDUCIAL MARKS S, T, U, V, W, ARE UNIQUE TO THE -- F-DISK WEDGE -- "N-SIDE" FACE.

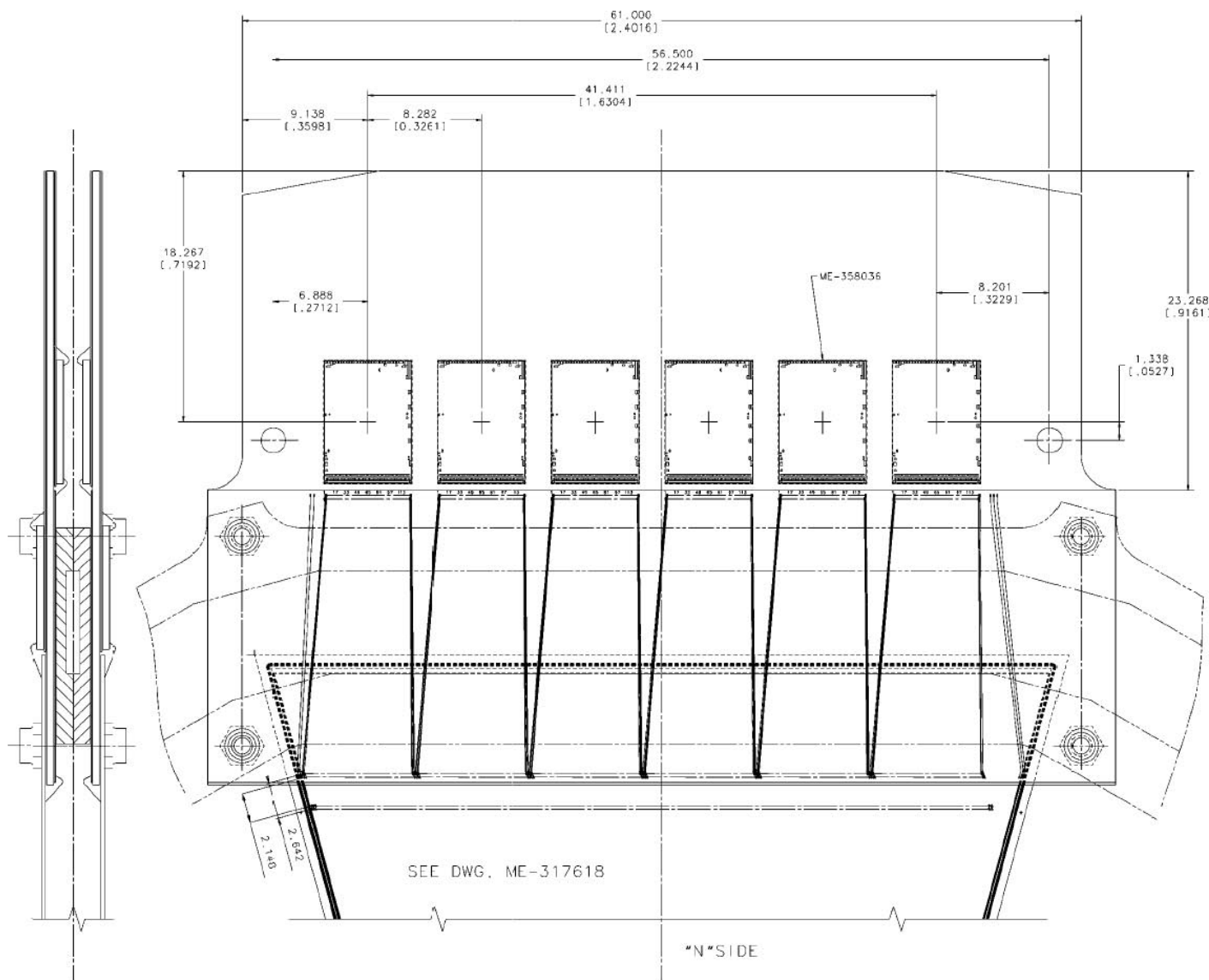


Plotted by cooper on 09-Sep-98

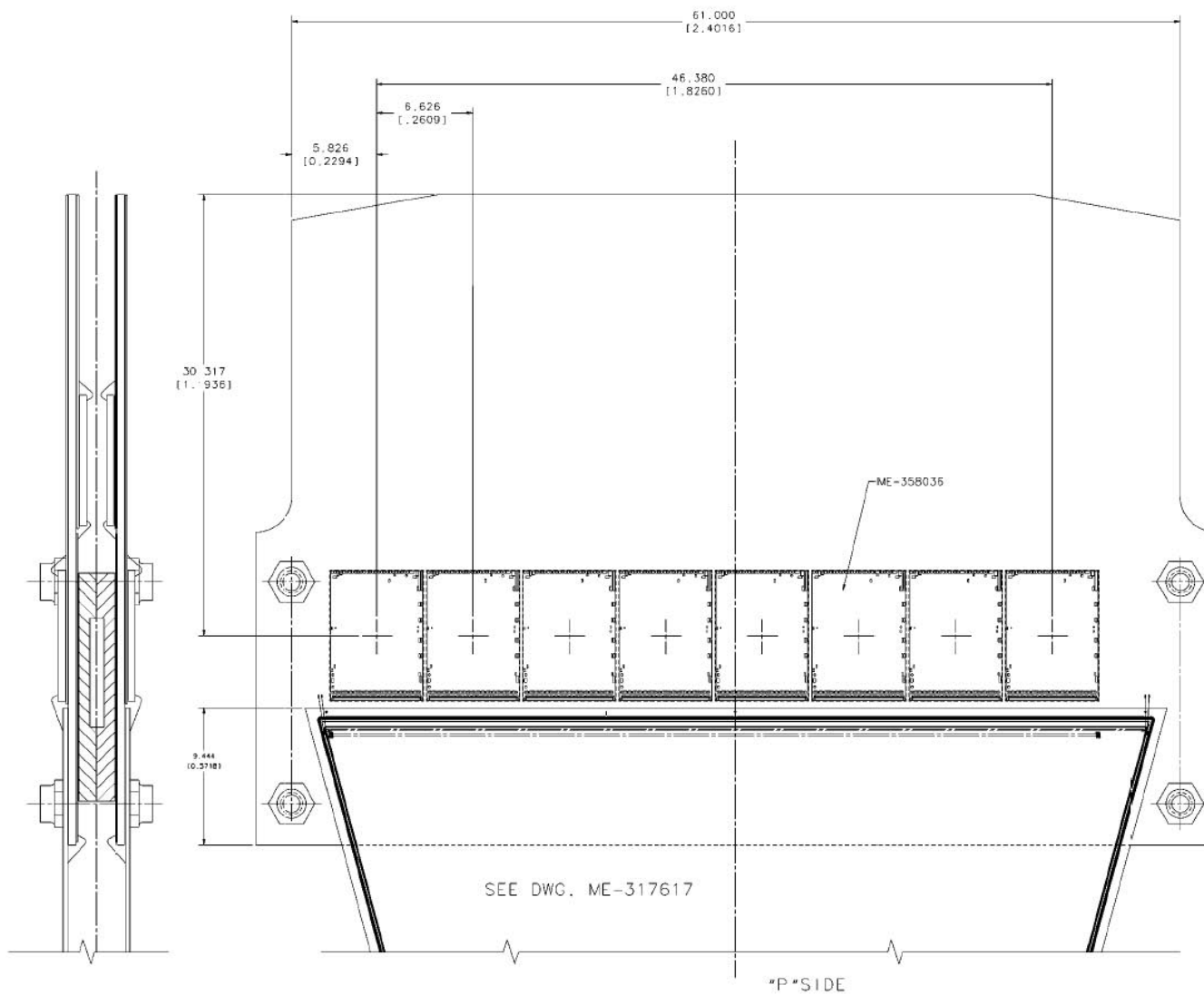
TECHNICAL EVALUATION ONLY !!  
F - DISK WEDGE - N SIDE  
30 JULY, 1996

REVISION	BY	DATE
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100	J. KAPLAN	30 JUL 96

FERMILAB NATIONAL ACCELERATOR LABORATORY  
UNITED STATES DEPARTMENT OF ENERGY  
D-ZERO UPGRADE  
F-DISK TRACKING-F-DISK  
F-DISK WEDGE - N SIDE - STRIP/FIDUCIAL DETAILS  
DRAWING NUMBER: 3823.112-ME-317618-01  
SHEET: 01  
DATE: 09-SEP-98



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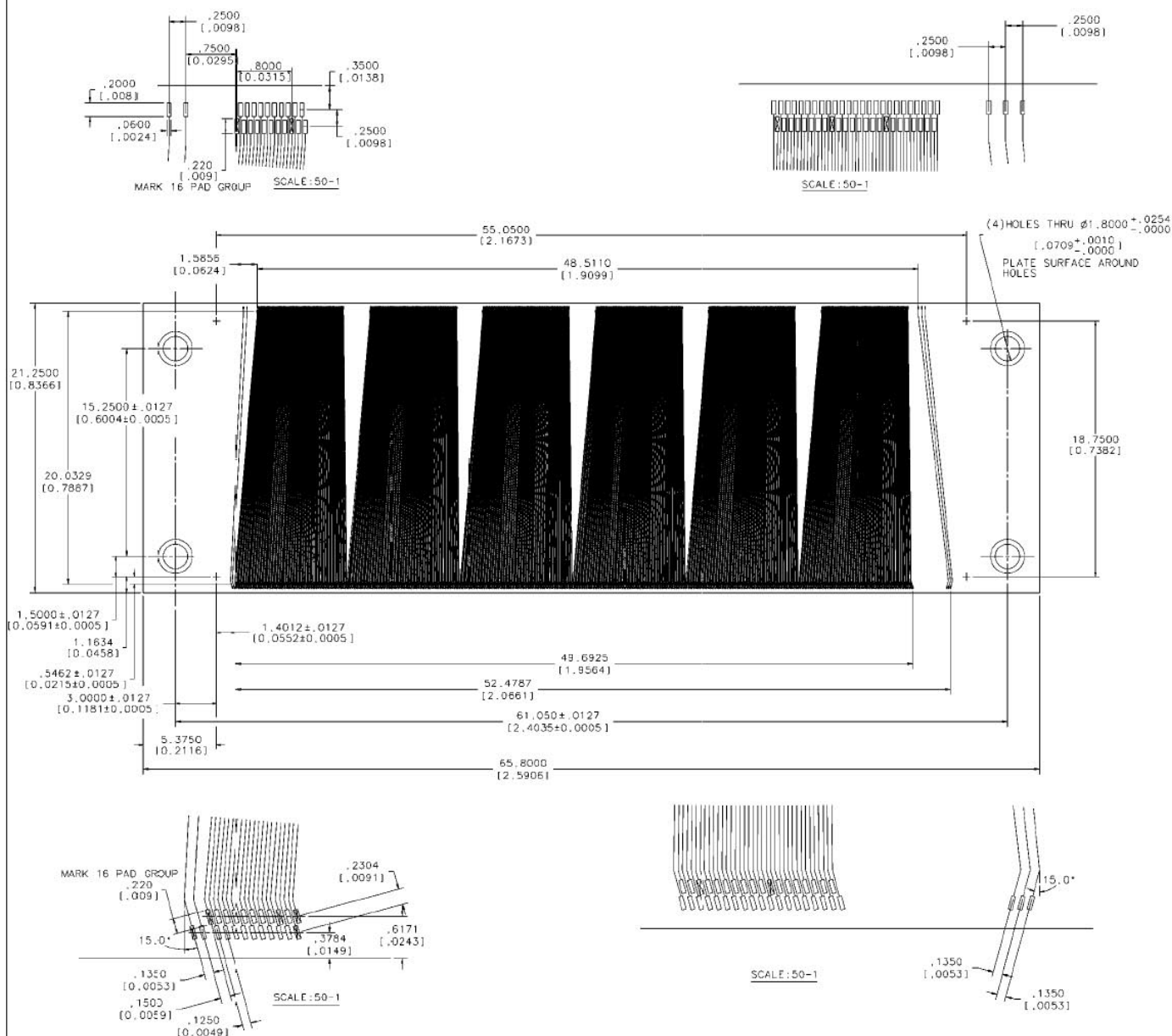


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FORM NATIONAL ACCELERATOR LABORATORY UNITED STATES DEPARTMENT OF ENERGY			
D-ZERO UPGRADE SILICON TRACKING F-DISK *P*SIDE HDI LAYOUT			
DATE	10-1	3823.112-ME-358108	REV.
CREATED BY	1-DEAS-VI	USER NAME	

16 Jan. 2003

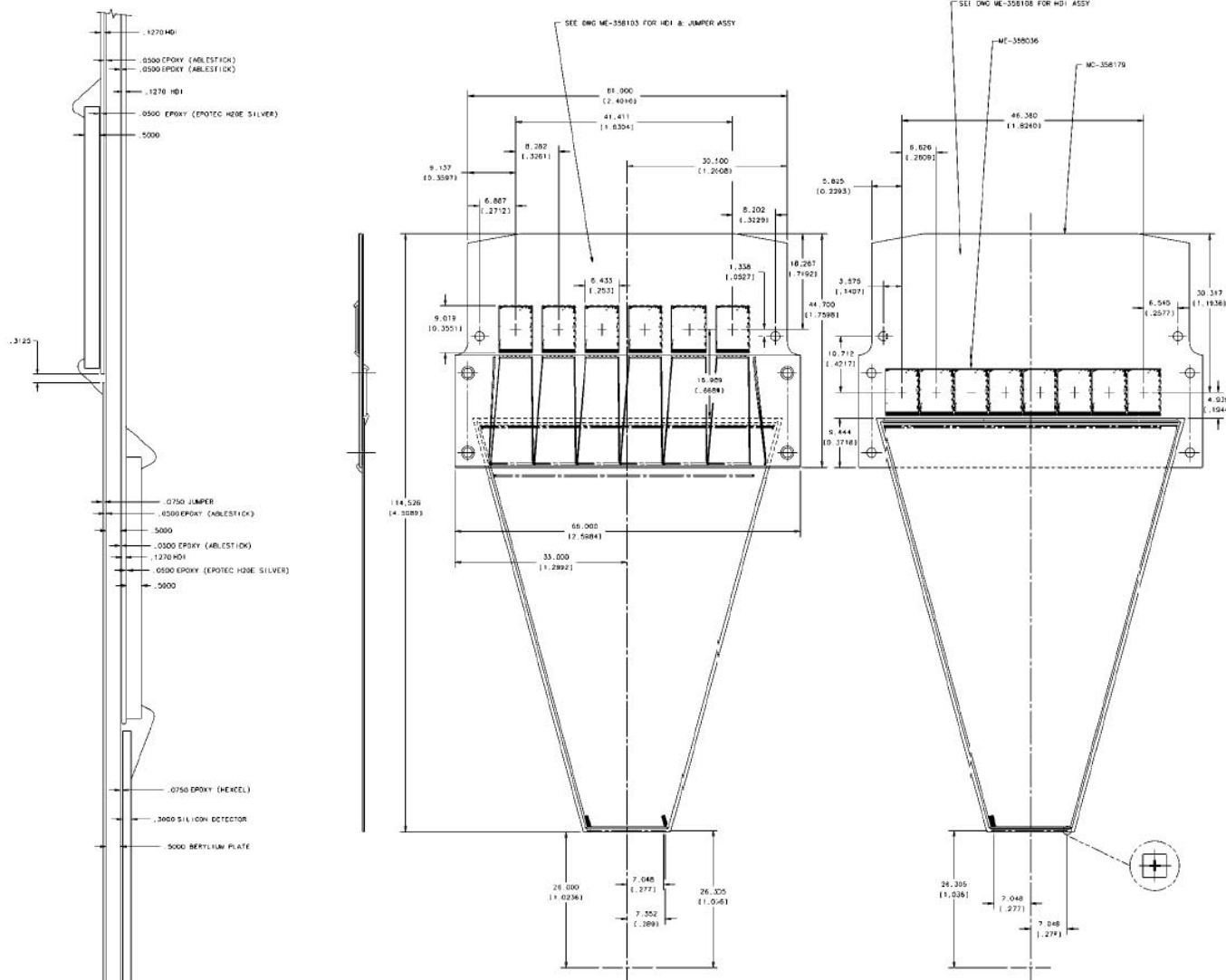
16 Jan. 2003



PRELIMINARY  
FOR ESTIMATING ONLY  
NOT FOR FABRICATION

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
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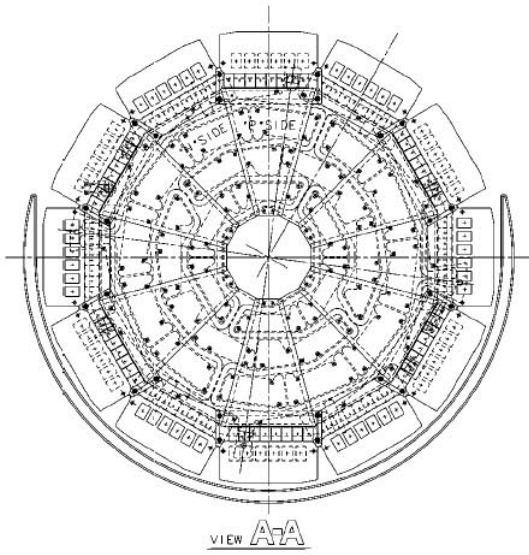
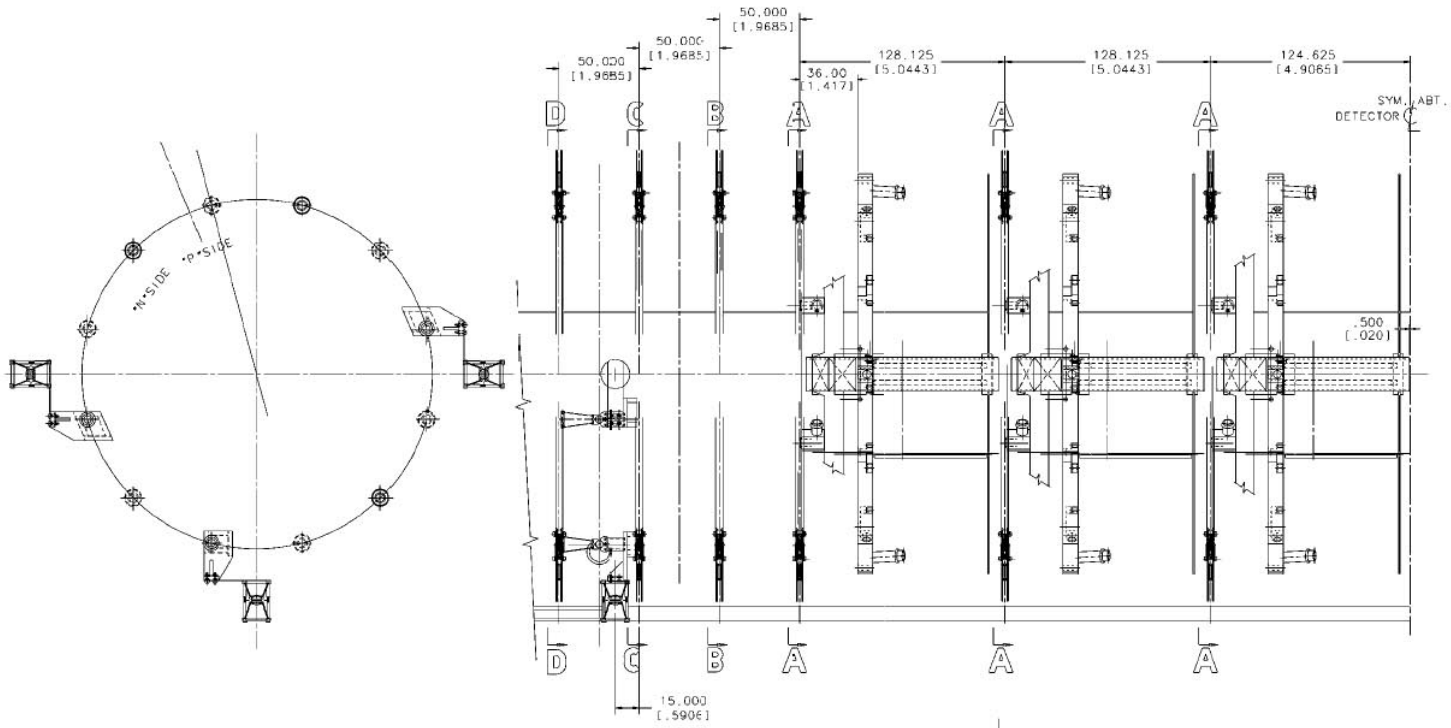


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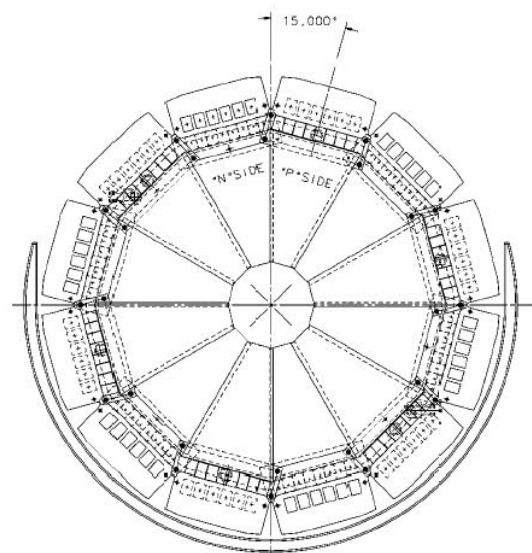


## F-disk Orientations, etc.

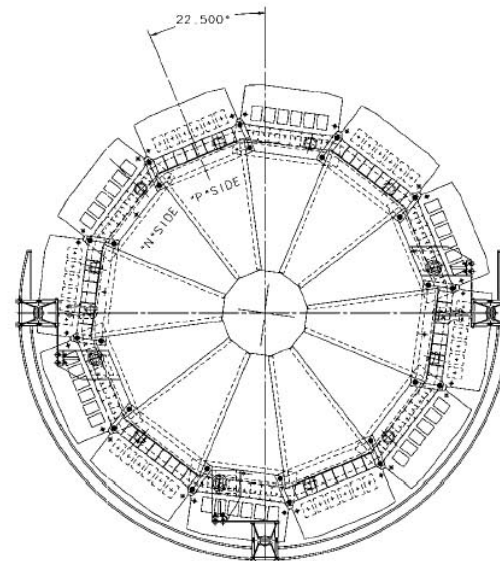
- F-disks attached to barrels all have the same azimuthal orientation.
- End F-disks are rotated with respect to those attached to barrels to help separate ghosts from tracks (see next transparency).
- A variety of spacings was considered for the end disks. The final spacing is 50 mm.
- See also, D0 note 3455.
- Many physicists were associated with F-disks. The primary Fermilab engineer was Joe Howell.
- Both F-disk and H-disk beryllium cooling / support channels came from Phenix Precision (Boston, Massachusetts area).



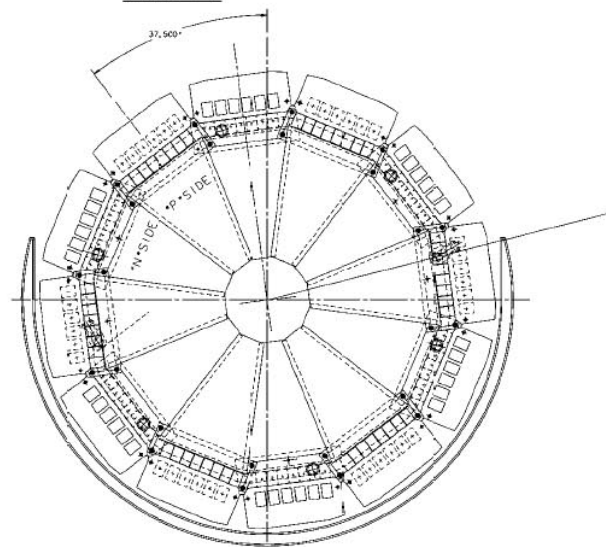
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JANIS CHOWELL SPECIFIED		DESIGNED BY	7/25/97
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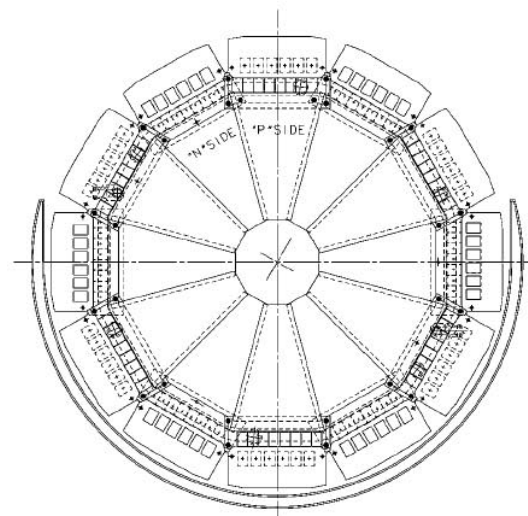
VIEW D-D



VIEW C-C



VIEW B-B



VIEW A-A

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
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FERMILAB NATIONAL ACCELERATOR LABORATORY  
UNITED STATES DEPARTMENT OF ENERGY

D-ZERO UPGRADE  
SILICON TRACKING F-DISK ASSY  
DETECTOR GENERAL ARRANGEMENT

3823.112-ME-358239

CREATED WITH T-SIDE ASSET

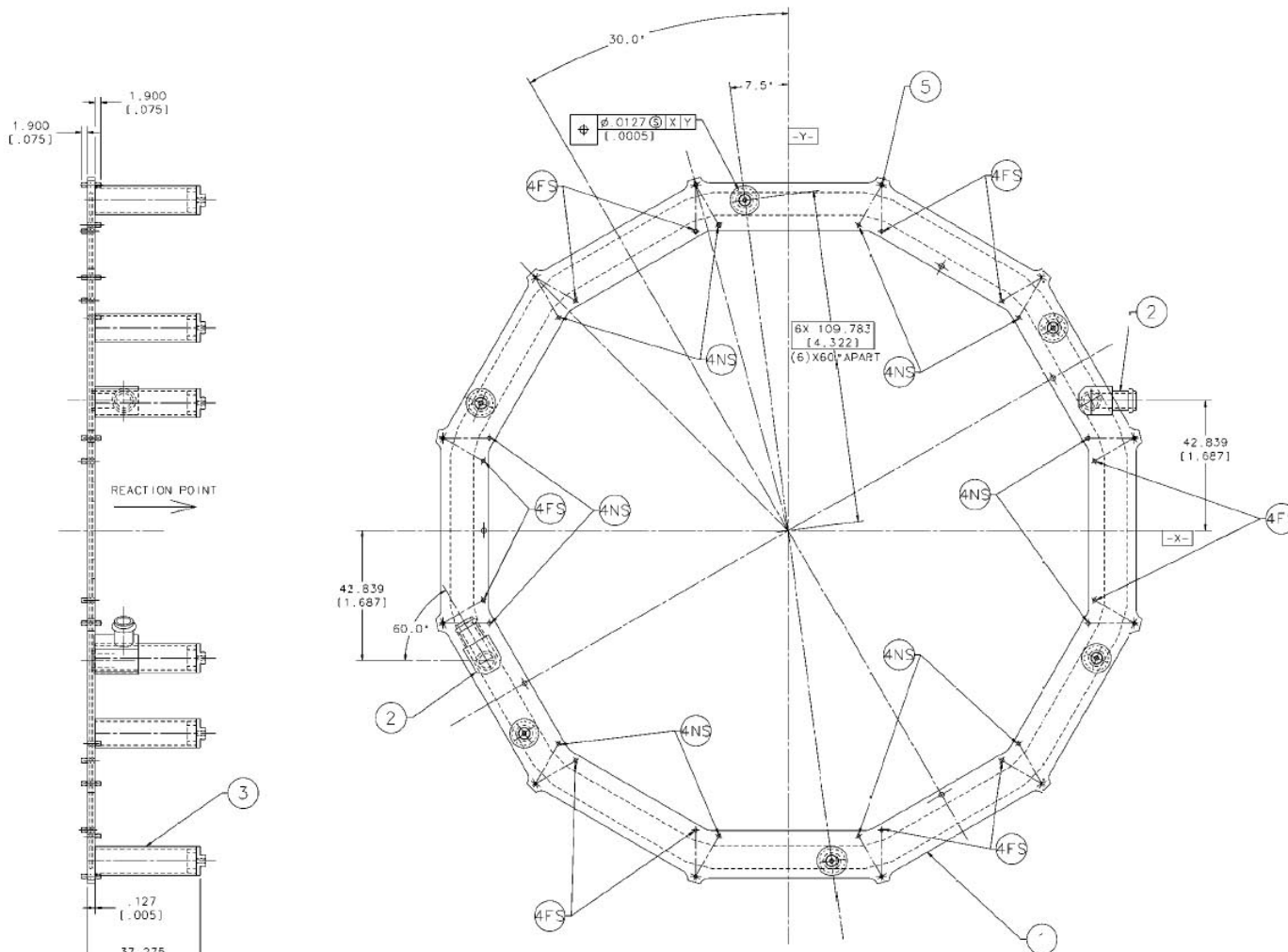
DATE

TIME

USER

NAME



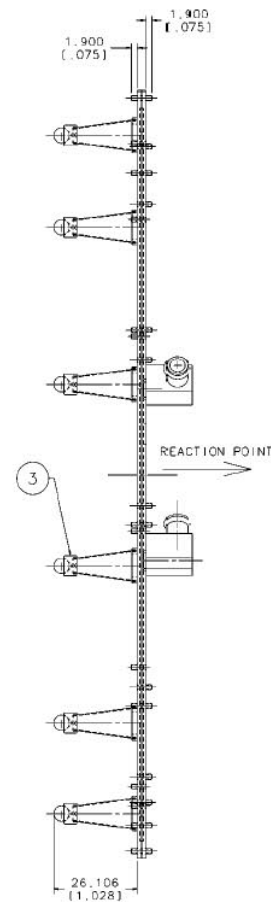


ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
5	MC-358443	LONG MOUNTING STUD	12
4	MC-358442	SHORT MOUNTING STUD	24
3	MC-358466	SUPPORT POST	6
2	MC-358086	90 DEG FITTING	2
1	ME-358034	F-DISK COOLING RING ASSY	1

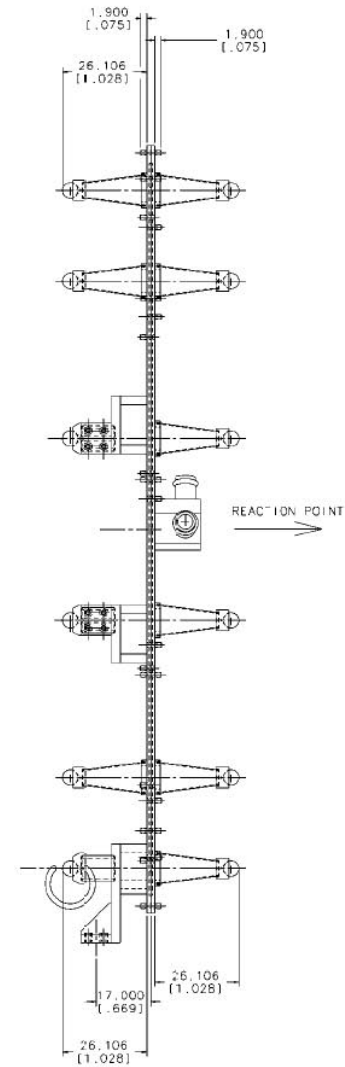
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1	10 1.025 1.01	1	10 1.025 1.01
1	10 1.025 1.01	1	10 1.025 1.01
1	10 1.025 1.01	1	10 1.025 1.01
1	10 1.025 1.01	1	10 1.025 1.01

FERMILAB  
 NATIONAL ACCELERATOR LABORATORY  
 UNITED STATES DEPARTMENT OF ENERGY  
 D-0 UPGRADE SILICON TRACKING  
 F-DISK A-COOLING RING  
 SUBASSEMBLY  
 2-1 3823.112-ME-358444  
 ORIGINATOR: F-DEAS-V11 USER NAME:

16 Jan. 2003

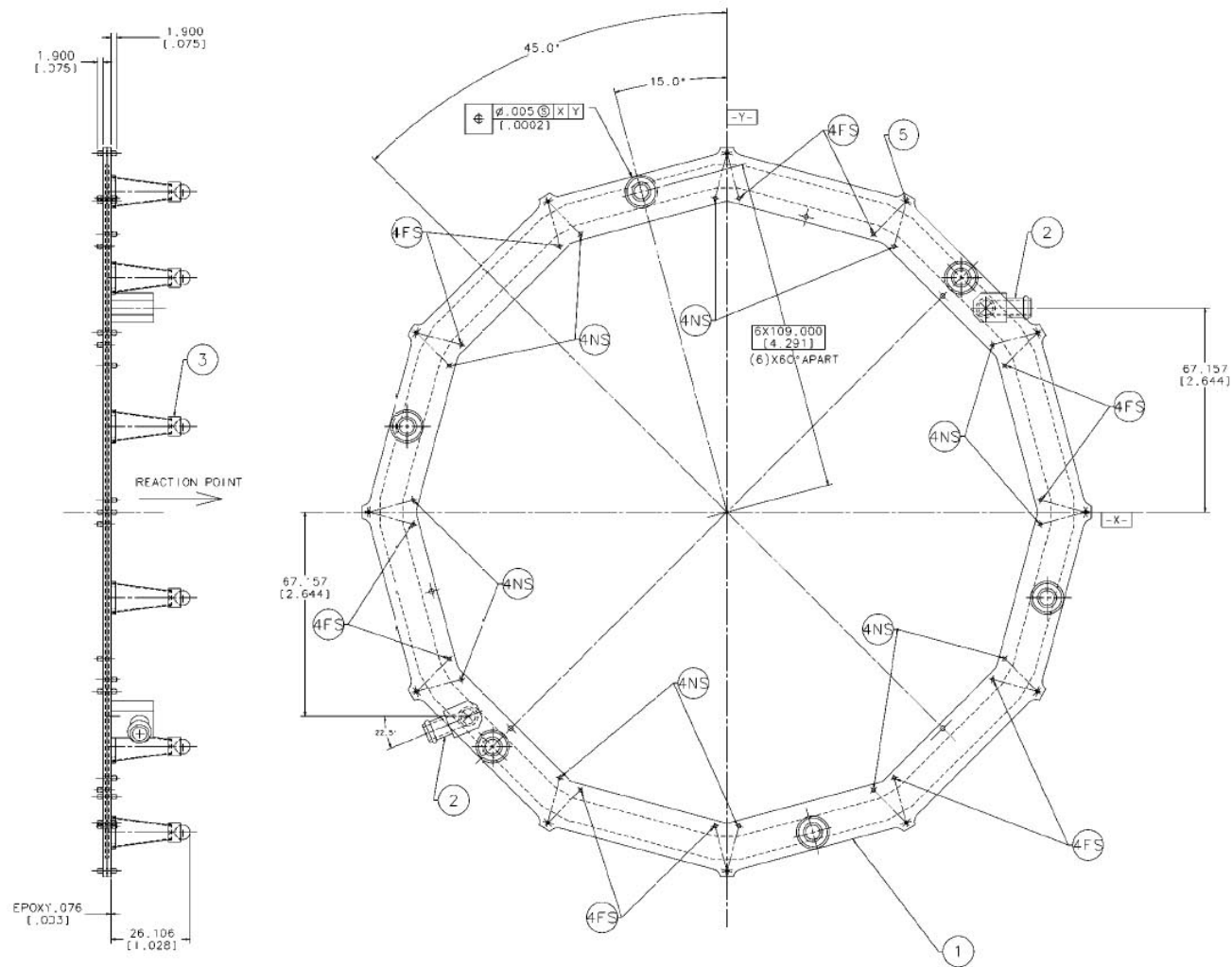


5	MC-558443	LONG MOUNTING STUD	12	
4	MC-55842	S-HORT MOUNTING STUD	26	
3	MC-55846	SUPPORT POST	6	
2	MC-558086	90 DEG FITTING	2	
1	ME-558034	F-DISK COOLING RING ASSY	1	
ITEM	PART NO.	DESCRIPTION - FROM OR SIZE	QTY.	
<b>DRAWING INFORMATION</b>				
DESIGNER'S SPECIFICATION		J. HONELL	5/7/55	
XX	XXX	DESIGN	G.S. TROTTER	5/7/55
XX	XXX	CHECKED	COO	5/7/55
APPROVED:				
BY: [Signature]		USED ON:		
FOR: [Signature]		DATE: [Signature]		
MATERIAL:				
FROM: NATIONAL ACCELERATOR LABORATORY UNITED STATES DEPARTMENT OF ENERGY				
D-O UPGRADE SILICON TRACKING F-DISK "B"-COOLING RING ASSY				
SCALE	1"=1"	3823.112-MC-558765	N/A	
CREATED BY	J. JESS MAE			



 FERMION NATIONAL ACCELERATOR LABORATORY UNITED STATES DEPARTMENT OF ENERGY			
D-O UPGRADE SILICON TRACKING *F*DISK *C*-COOLING RING ASSY			
DATE 2-1	I/O 3823.112-ME-358766	ORDER NO. 3823.112-ME-358766	A/C 3823.112-ME-358766
CREATED WITH THE I/O-DEVELOPER		ENTER NAME	

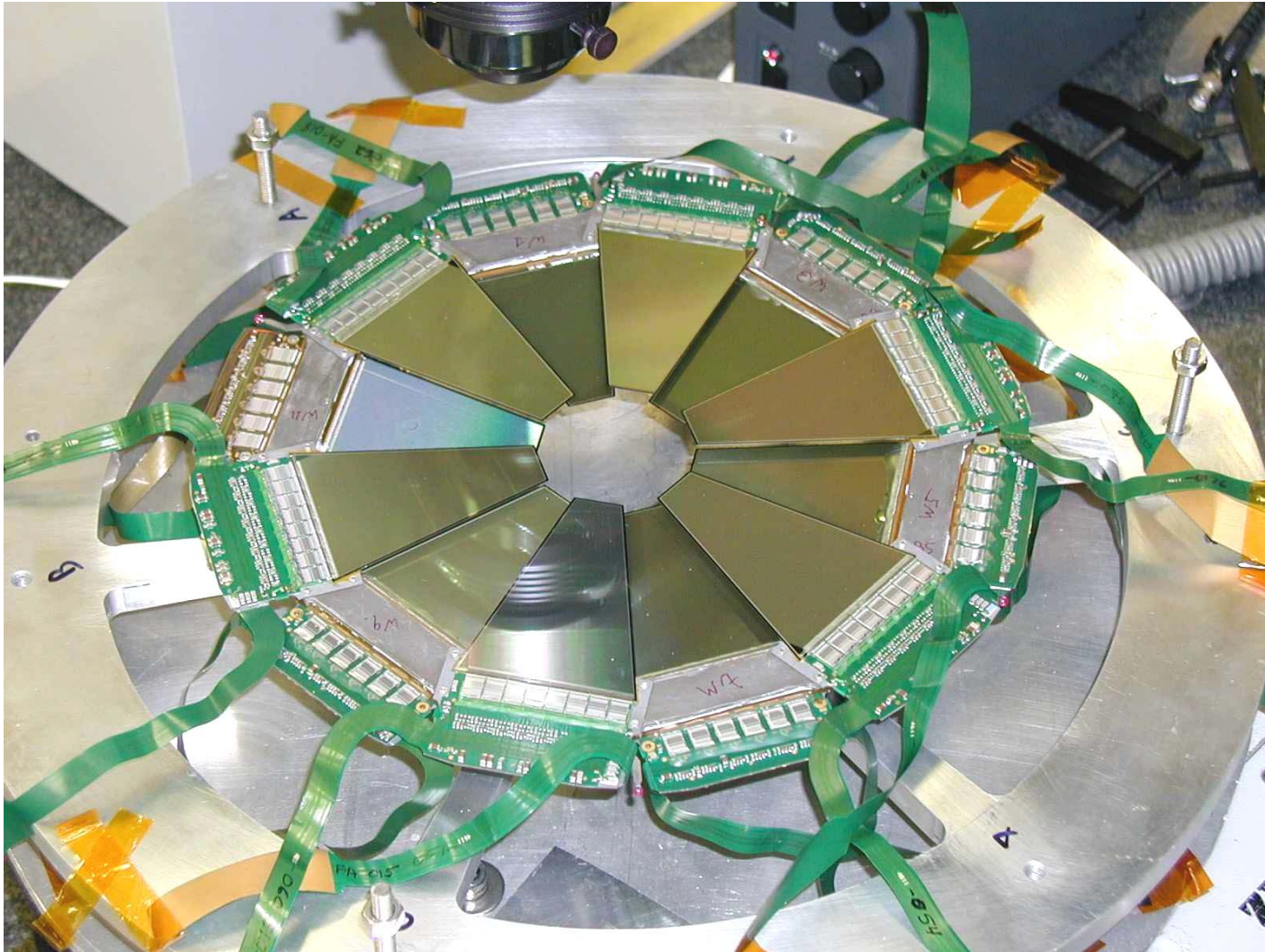
CA 6116



PRELIMINARY DRAWING



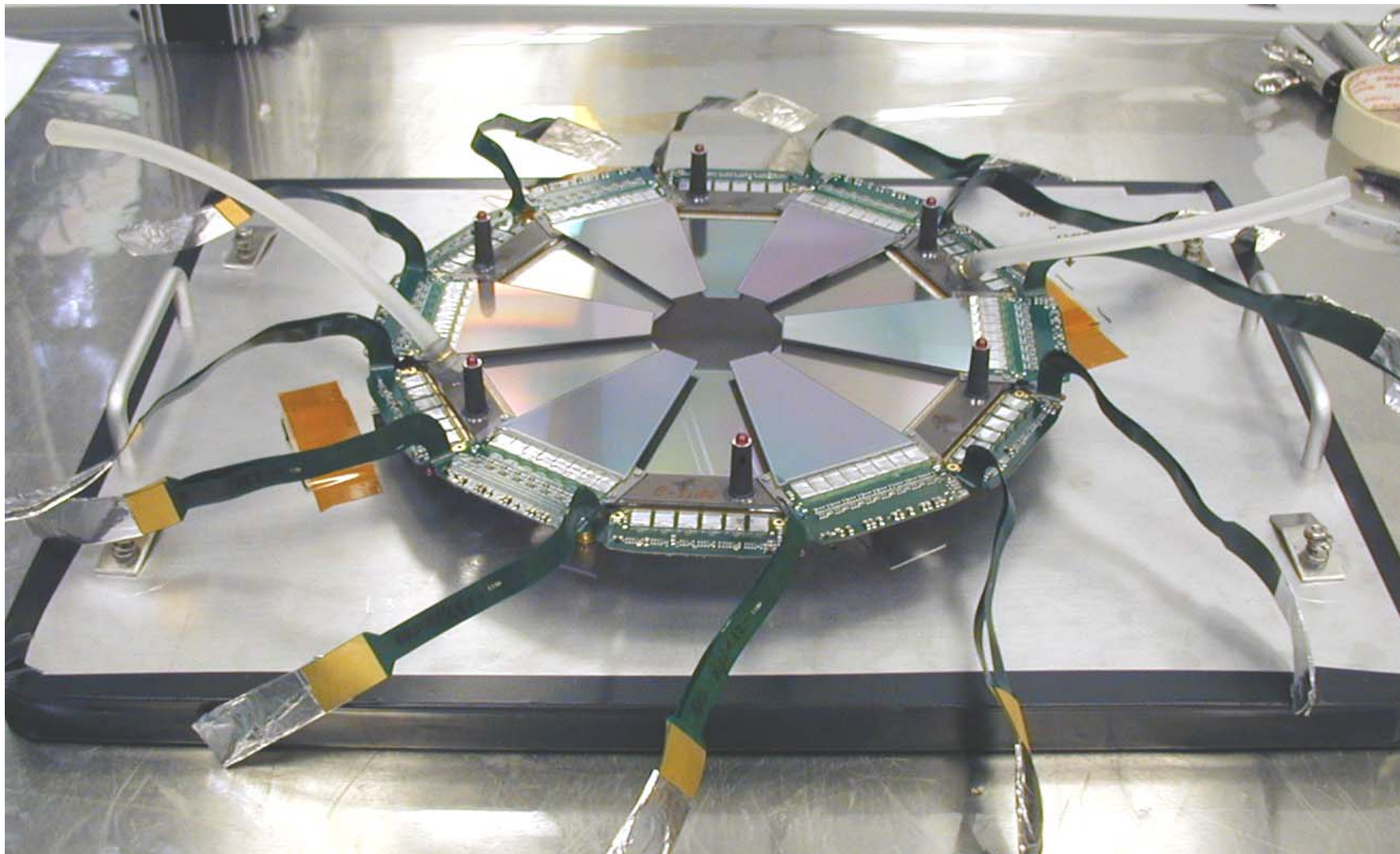
# F-wedge Installation on Cooling Ring







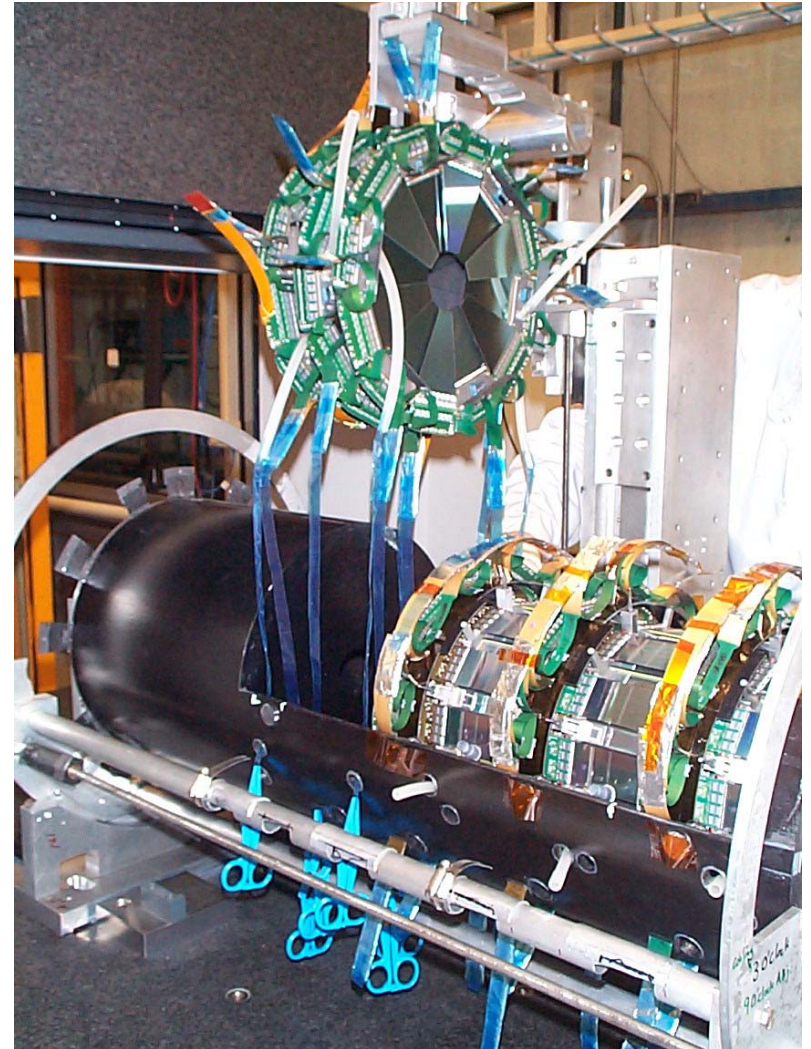
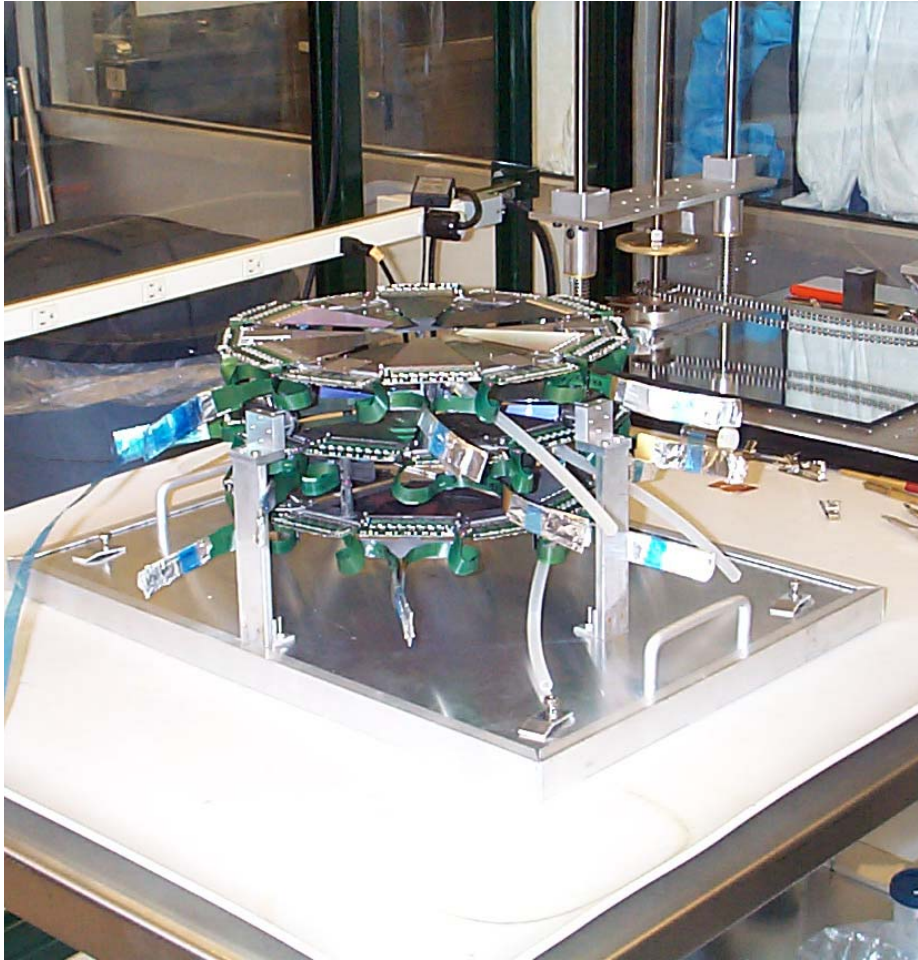
# F-disk Assembly







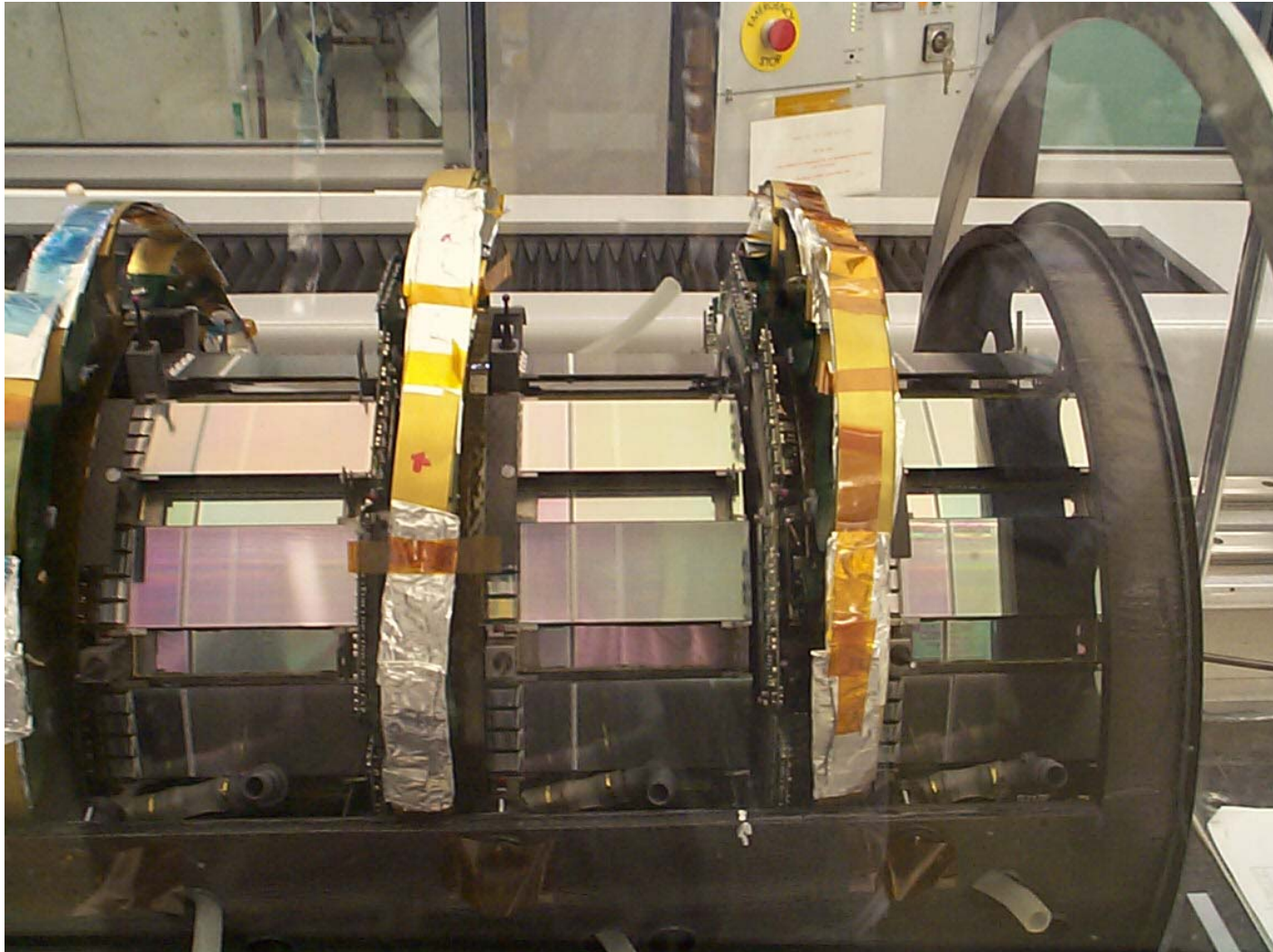
## Assembly & Installation of End F-disk Module





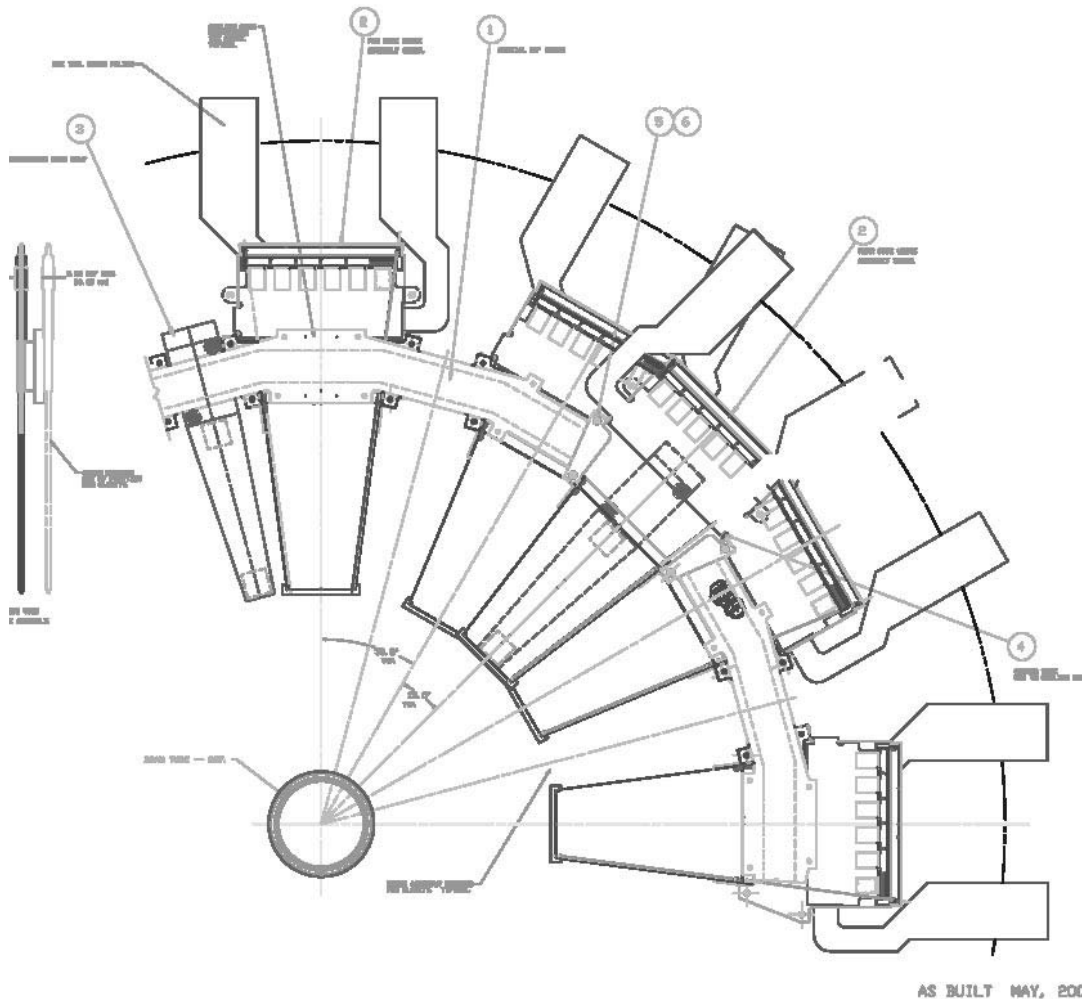


## Barrel / F-disk Modules in Support Cylinder





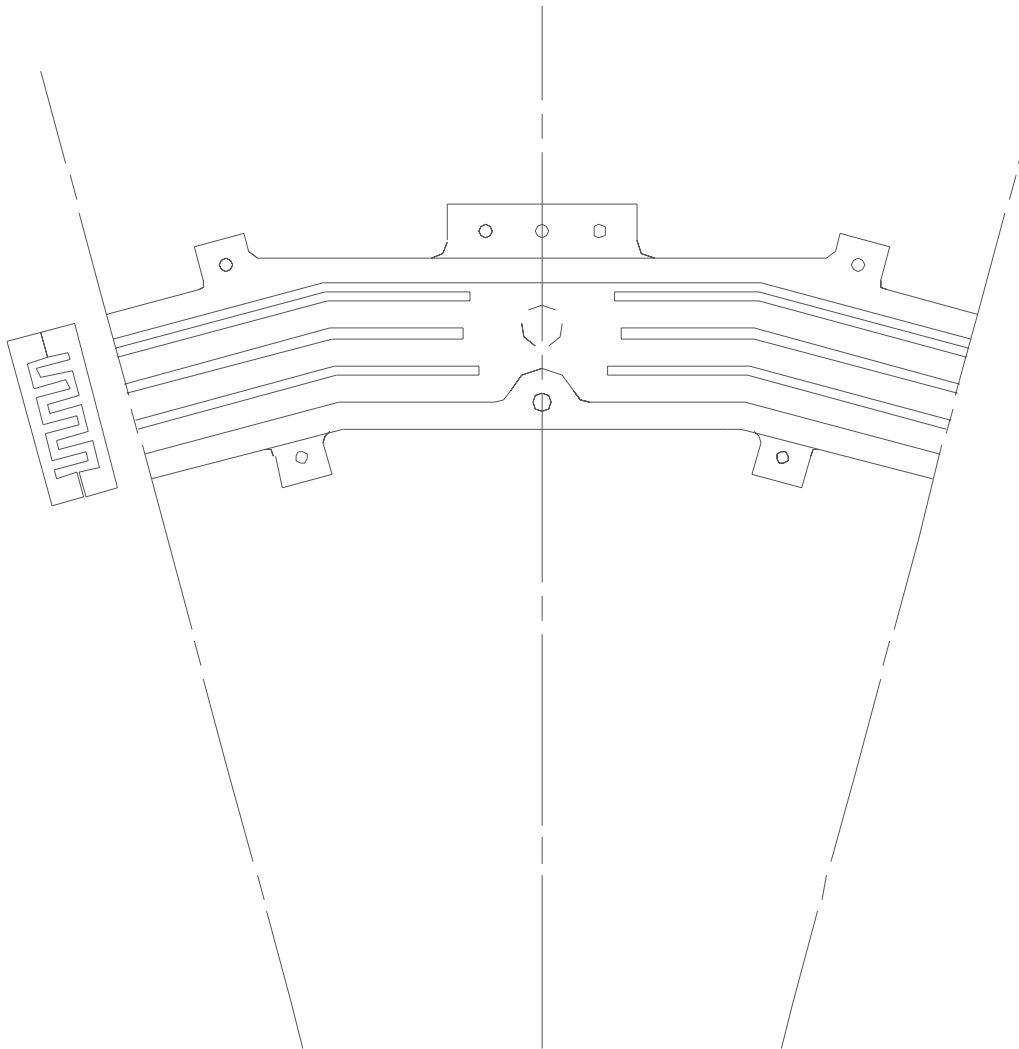
# H-disk Design



- Silicon IR = 95.865 mm, OR = 236.109 mm at wedge centerline
- Readout mounts on the outer of two wedge sensors at a given  $\phi$
- Pitch adapters on silicon substrates match sensor pitch to SVX-IIe pitch.
- Beryllium substrates position inner and outer sensors with respect to cooling channel
- Back-to-back wedges provide stereo
- Effective stereo angle =  $15^\circ$
- Trace pitch = 40  $\mu\text{m}$
- Readout pitch = 80  $\mu\text{m}$



# H-disk Cooling / Support Channel

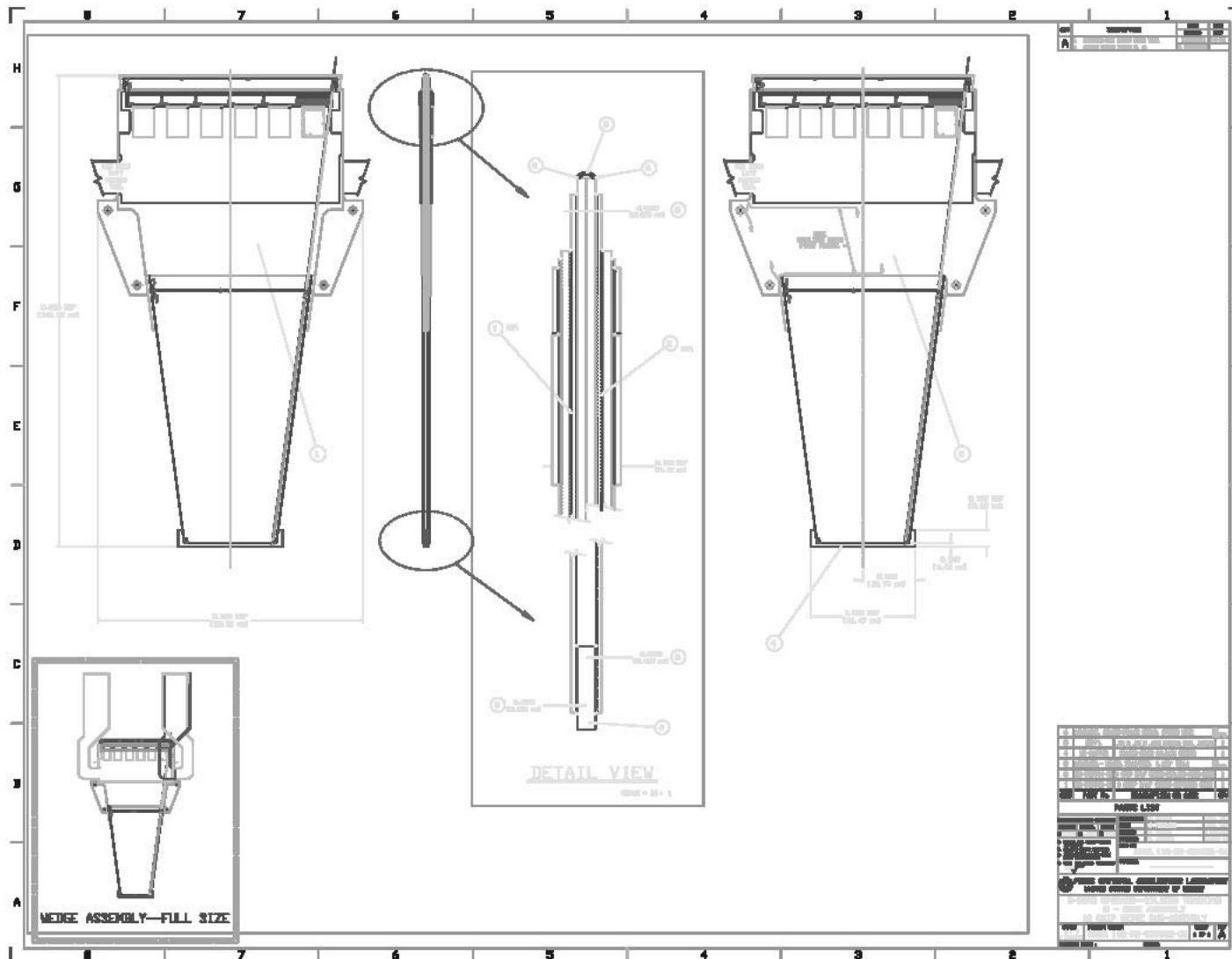


- *Considerable effort went into optimizing cooling channel geometry to obtain good heat transfer while maintaining acceptable pressure drop.*
- *The h-disk channels are the most extreme case, with a fingered design to increase the effective surface area.*

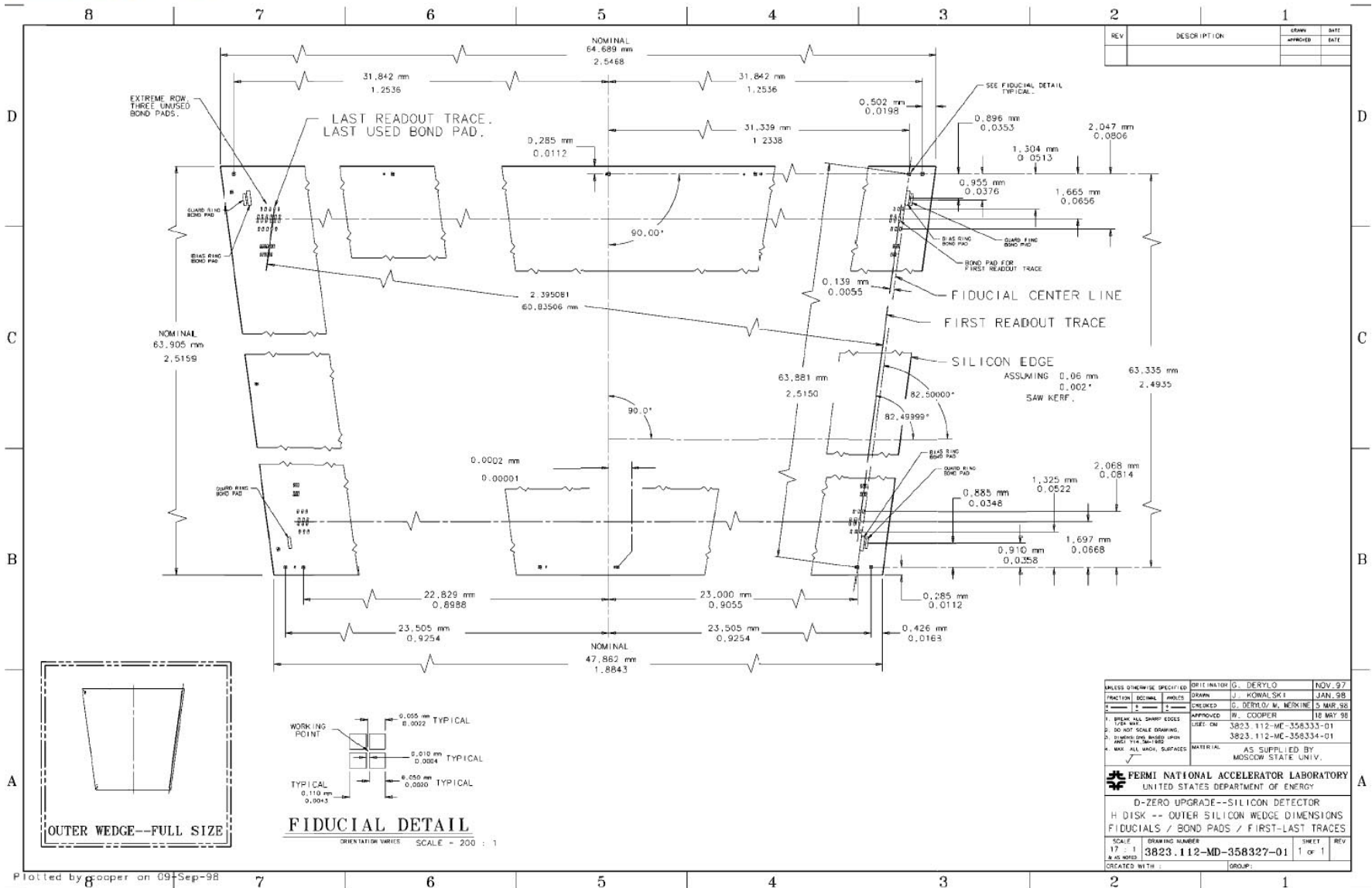


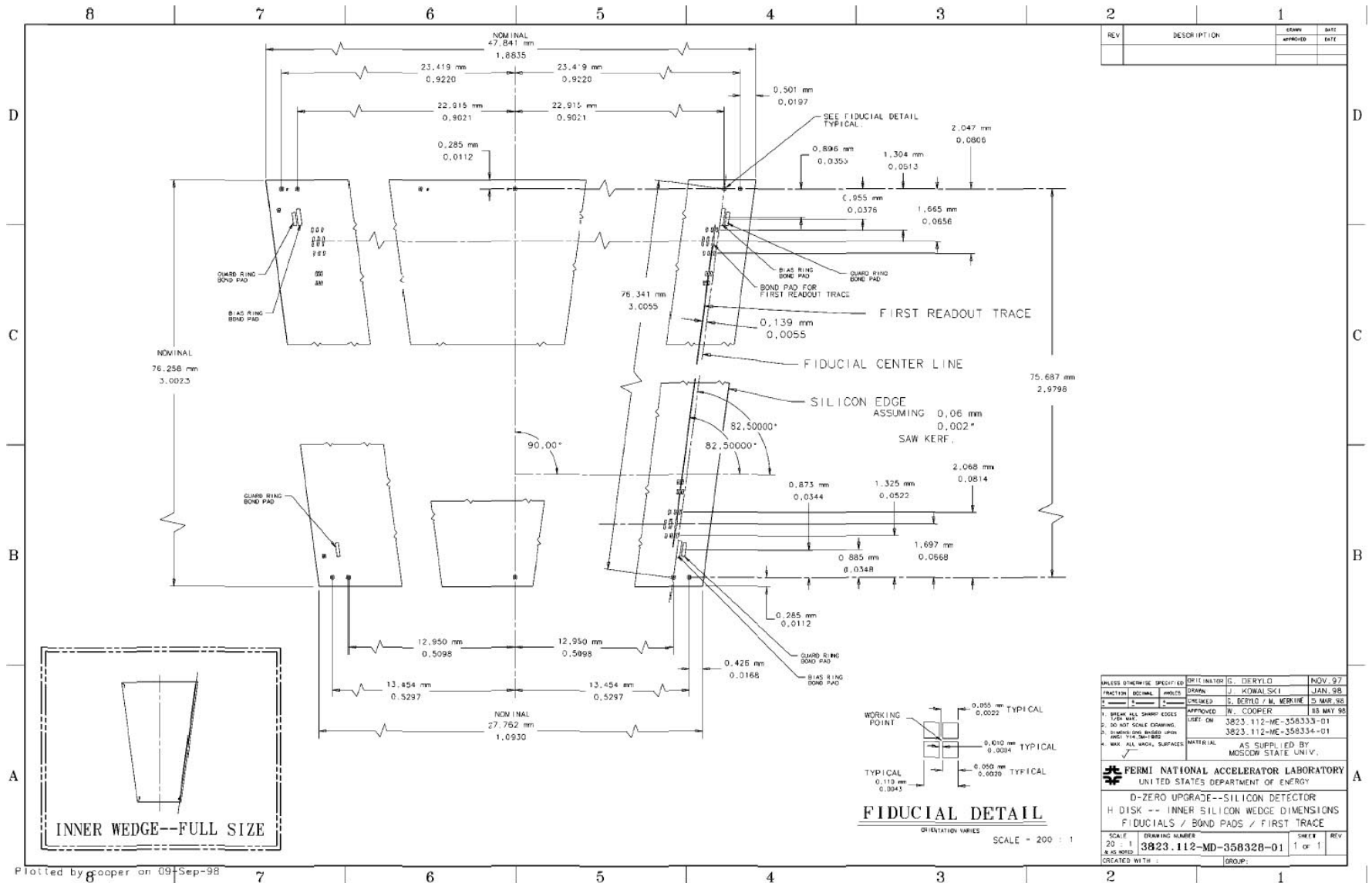


# H-disk Four-Sensor Wedge

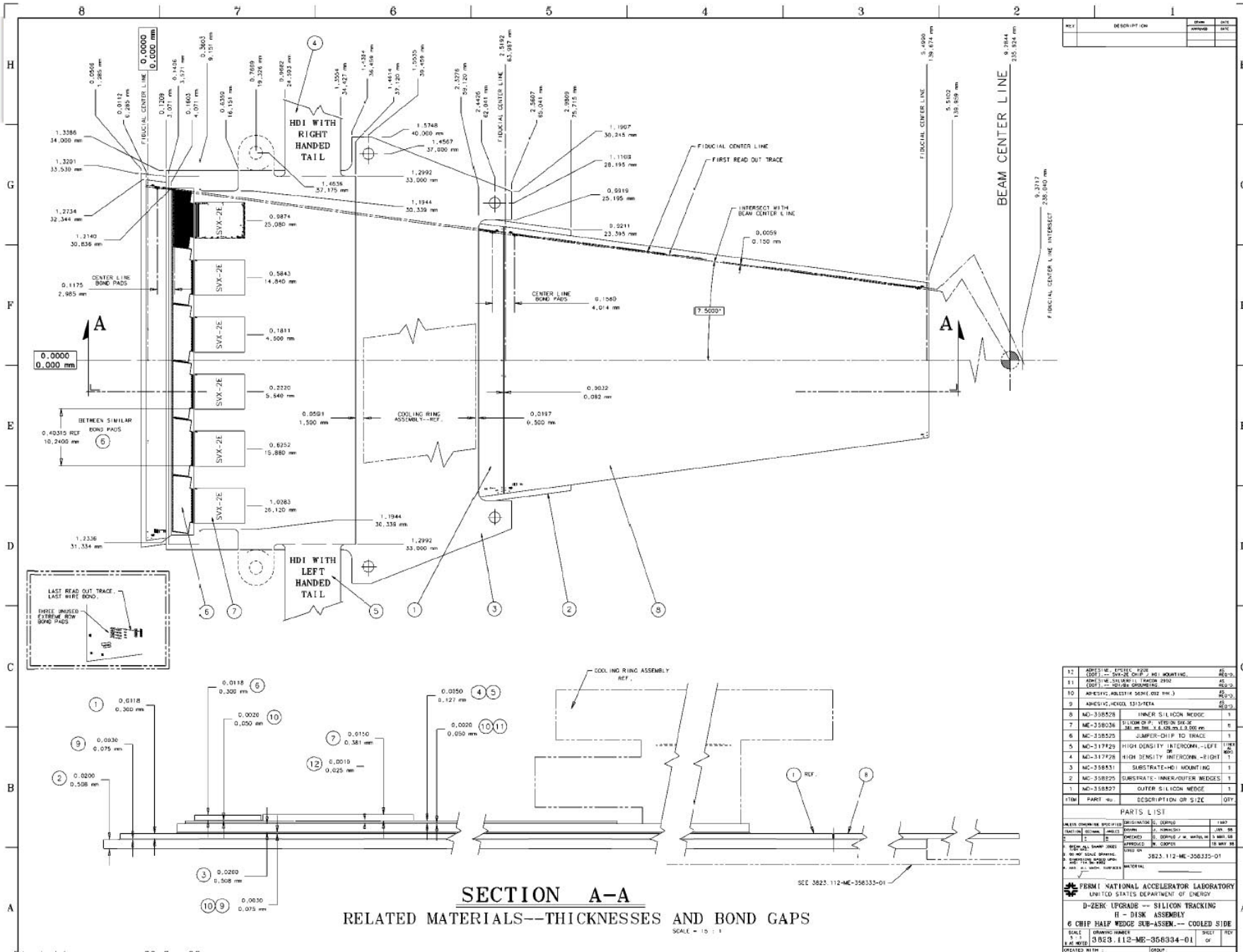


- Probably the most ambitious of the Run II designs
- Inner and outer wedges are aligned on their beryllium readout substrate to form a “Half-wedge”.
- Two half-wedges are aligned back-to-back to form a “Full-wedge” and provide stereo.









12	ADDITIONAL INTERFERE	REF.
11	ADDITIONAL INTERFERE	REF.
10	ADDITIONAL INTERFERE	REF.
9	ADDITIONAL INTERFERE	REF.
8	ADDITIONAL INTERFERE	REF.
7	ADDITIONAL INTERFERE	REF.
6	ADDITIONAL INTERFERE	REF.
5	ADDITIONAL INTERFERE	REF.
4	ADDITIONAL INTERFERE	REF.
3	ADDITIONAL INTERFERE	REF.
2	ADDITIONAL INTERFERE	REF.
1	ADDITIONAL INTERFERE	REF.
<b>PARTS LIST</b>		
ITEM	PART NO.	DESCRIPTION OR SIZE
1	3823.112-ME-356333-01	3823.112-ME-356333-01
2	3823.112-ME-356333-01	3823.112-ME-356333-01
3	3823.112-ME-356333-01	3823.112-ME-356333-01
4	3823.112-ME-356333-01	3823.112-ME-356333-01
5	3823.112-ME-356333-01	3823.112-ME-356333-01
6	3823.112-ME-356333-01	3823.112-ME-356333-01
7	3823.112-ME-356333-01	3823.112-ME-356333-01
8	3823.112-ME-356333-01	3823.112-ME-356333-01
9	3823.112-ME-356333-01	3823.112-ME-356333-01
10	3823.112-ME-356333-01	3823.112-ME-356333-01
11	3823.112-ME-356333-01	3823.112-ME-356333-01
12	3823.112-ME-356333-01	3823.112-ME-356333-01







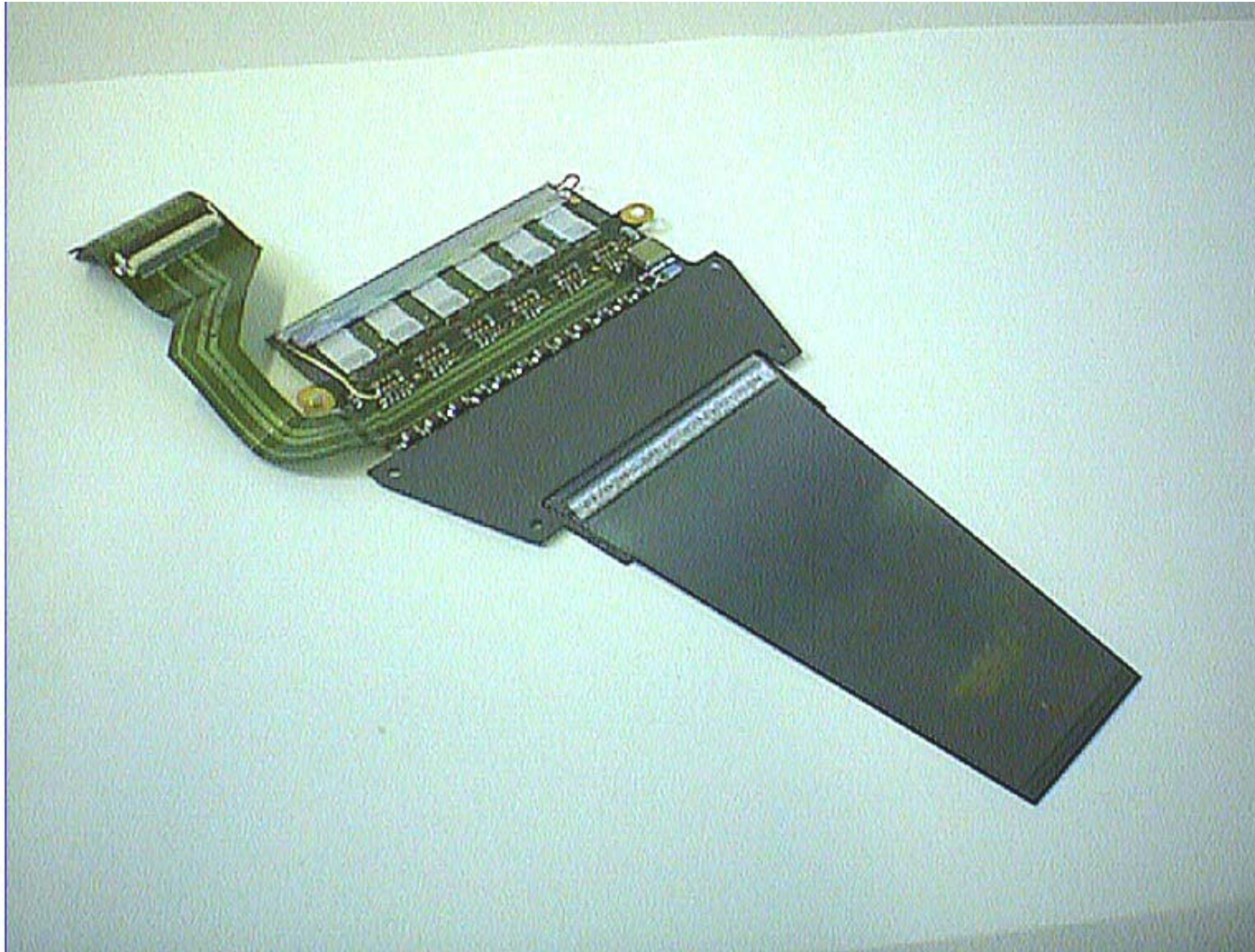
## H-disk People

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- We benefited from strong Russian and Kansas State participation on H-disks. The primary Fermilab engineer was Greg Derylo. Greg Sellberg was crucial to the development of the dual camera alignment system.

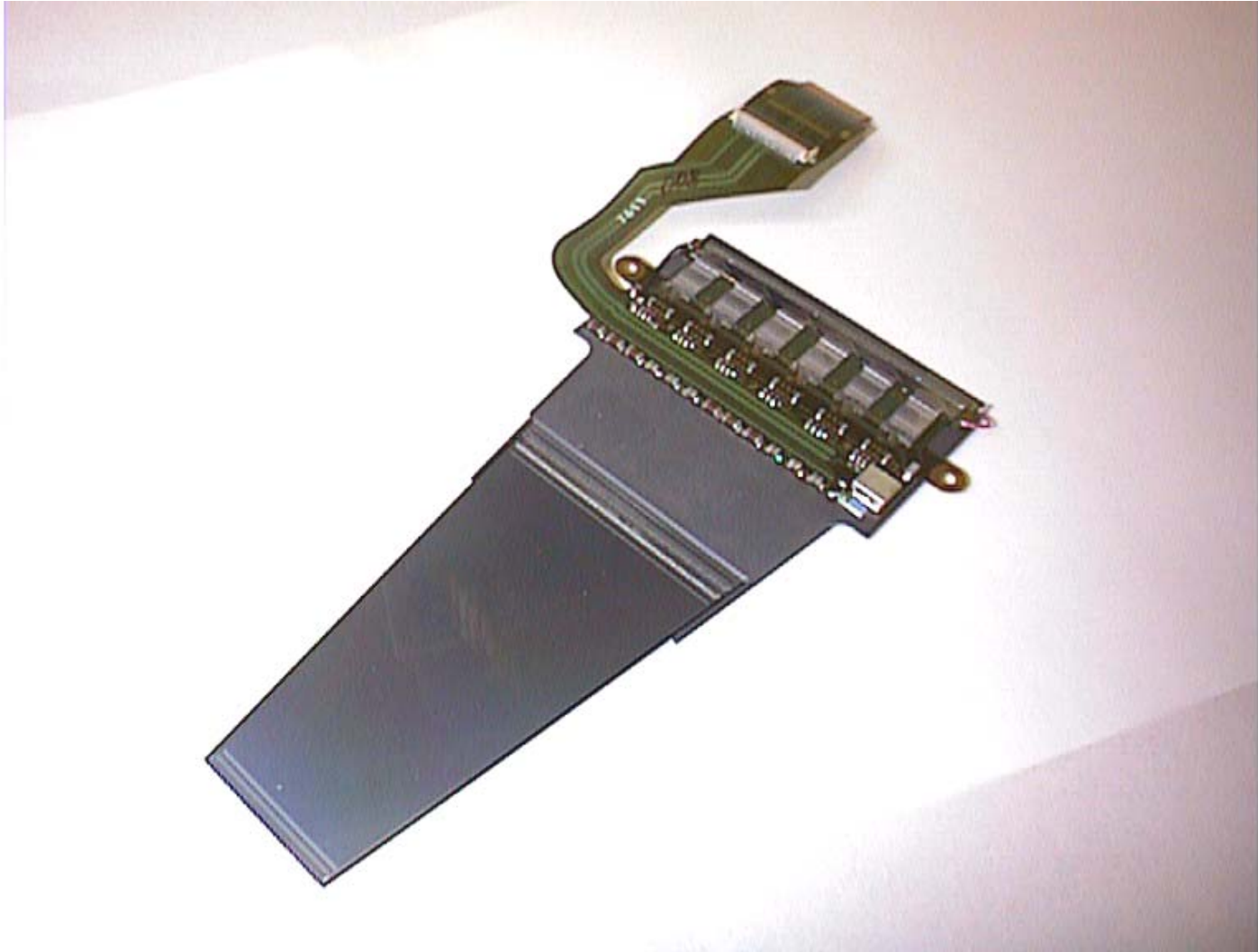


# Half-wedge Cooled Assembly





# Half-wedge Exposed Assembly

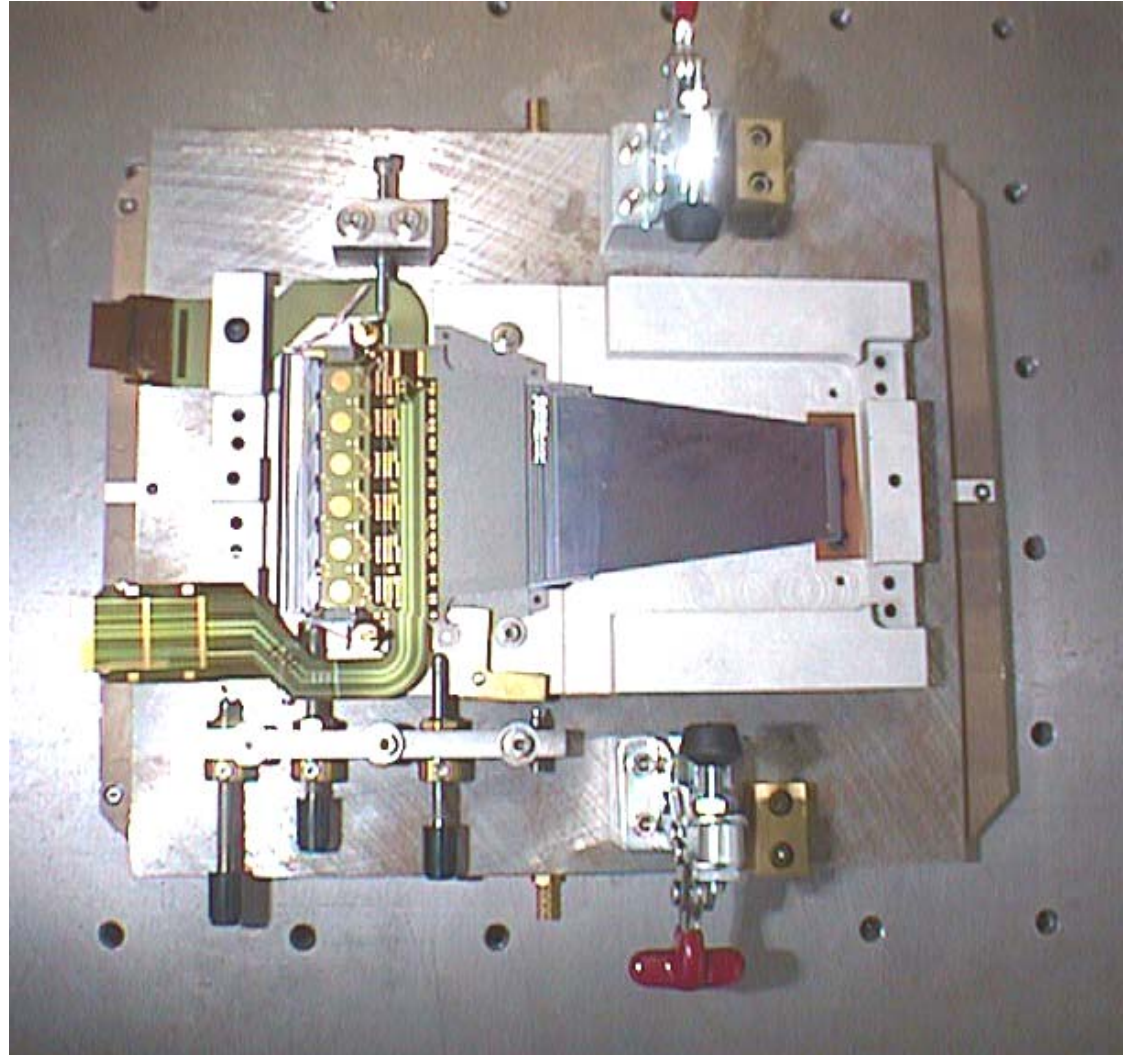






# Full-wedge Back-to-back Alignment

- Dual, collinear Nikon camera system on a Zeiss UMM500 CMM







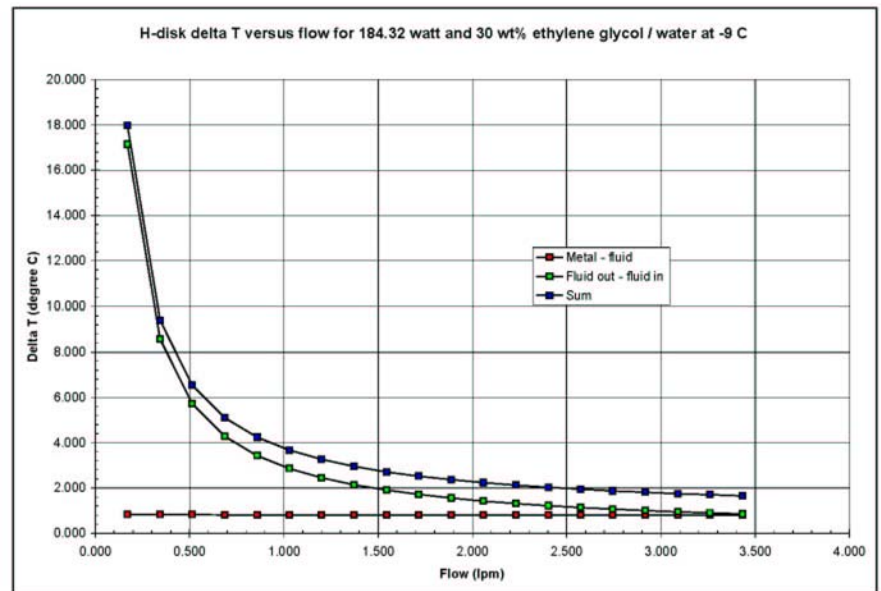
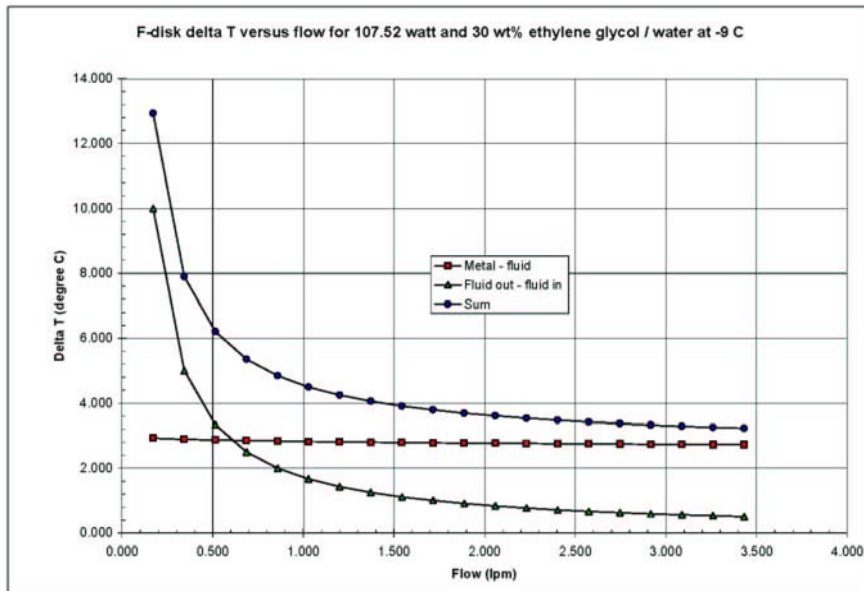
# Cooling

- All cooling is based upon the flow of an ethylene glycol - water mixture through beryllium channels which are in good thermal contact with sensor assemblies.
  - ♦ The original design assumed a coolant temperature of  $0^{\circ}$  to  $+5^{\circ}$  C and a heat load of 0.64 watts per SVX chip.
  - ♦ A conservative design and lower chip power dissipation allow colder operation.
  - ♦ The present coolant temperature is  $-9^{\circ}$  C; actual power dissipation is 0.46 watts per SVX chip.
  - ♦ Sub-atmospheric operation limits the delta P available. The final design delta P is 8 psi from the end of a supply manifold to the end of a return manifold.
  - ♦ The cooling system has worked reliably since day 1.
- Sensor support structure designs have been chosen which minimize thermal positional distortions in cooling from room temperature to operating temperature.
- Silicon temperature within a given sensor varies with location.



# Cooling

- Temperature difference between beryllium metal surface to which wedges mount and bulk coolant for  $-9^{\circ}\text{C}$  coolant
  - ◆ Orifices are used to balance flows.
  - ◆ Nominal F-disk flow = 1.35 lpm; actual silicon temperature  $< -4^{\circ}\text{C}$
  - ◆ Nominal H-disk flow = 1.30 lpm; actual silicon temperature  $< -5^{\circ}\text{C}$
  - ◆ Final SVX-IIe chip dissipation is 70% of original design value, so temperature rises are proportionately lower than those shown below.





# Conclusion

- The simultaneous design development and construction of barrels, F-disks, H-disks, and associated fixturing, with limited previous DO silicon experience, was a substantial undertaking.
- Most of the designs are well-documented with drawings.
- Design took 3+ years; procurement, fabrication, assembly, testing, and installation took 4 years.
- The tracker has been in operation since the spring of 2001.
- The mechanical designs have proven to be sound and alignment has been very good.